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South African Food Security and Climate Change: Agriculture Futures

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Abstract

The projected changes in planted area, yield per area, net exports/imports and prices for five major agricultural crops in South Africa were simulated using the projections of four Global Circulation Models (GCMs) under three socio-economic scenarios. The GCM projections show consistent strong warming over the subcontinent, but disagree with respect to future precipitation, from slight wetting (particularly on the eastern side) to overall slight drying. The future crop yields were simulated using the DSSAT crop model suite. The planted area, commodity prices and net exports were simulated using the IMPACT global food trade model. The results indicate slightly rising to stable yields per unit area up to 2050, despite climate change, largely due to the inbuilt assumption of ongoing agronomic and genetic improvements. Vulnerability to food insecurity increases in the future under all but the most optimistic development scenarios, and is exacerbated by climate change, especially through global-scale, market- related mechanisms. Policies to increase local agricultural production in South Africa, decrease climate sensitivity and access to international markets are highlighted.

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Keywords Climate change; crop production; scenarios; food security; futures; modeling

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1 Introduction

South Africa remains committed to improve food security for its people. This is reflected in in government programs such as the Integrated Food Security and Nutrition Program which aims to eradicate hunger, malnutrition and food insecurity by 2015; the Household Food Production Program which provides food production packages and establishes vegetable gardens; and the Farmer Support Program which provides loans through the micro-agricultural financial institutions (DAFF 2002, DAFF 2012). The impact of climate change on food security needs to be identified and characterized so that appropriate policies and strategies are put in place.

Understanding trends in agricultural production and trade, in relation to climate change and population growth is vital for national planning and the development of adaptation and mitigation strategies. This report sets out to highlighting some of the trends and scenarios.

The first part of this paper is an overview of the current food security situation, the underlying natural resources available in South Africa and the drivers that led to the current state, focusing on income and population growth. The second part reviews the South Africa-specific outcomes of a set of scenarios for the future of global food security in the context of climate change. These country-specific outcomes are based on IMPACT model (Rosegrant et al. 2008) runs undertaken in July 2011.

The Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), Working Group 1, defines climate as 'average weather'. Climate is usually described in terms of the mean and variability of temperature, precipitation and wind over a period of time, ranging from months to millions of years (the classical period is 30 years) (Le Treut et al. 2007: 96).

The increase of greenhouse gas concentrations in the atmosphere is raising average temperatures. The consequences include changes in precipitation patterns, more frequent extreme weather events, and shifting seasons. The accelerating pace of climate change, combined with global population and income growth, threatens food security everywhere.

Agriculture is vulnerable to climate change in a number of dimensions. Higher temperatures eventually reduce yields of crops and livestock and tend to encourage pathogen proliferation. Greater variation in precipitation increases the likelihood of short-run crop failures and long-run production declines. Although there might be gains in some crops in some regions of the world, the overall impacts of climate change on agriculture are expected to be negative above a global mean temperature rise of 2 ° C, threatening global food security. The impacts are

- Direct, on crops and livestock productivity
- Indirect, through the availability and price of food on national and international markets
- Indirect, via income from agricultural production both at the farm and country levels

2 Regional impacts of climate change

While the global projections in climate change are increasingly well known, great uncertainty remains about how climate change will play out in specific locations. To understand the significant uncertainty in how these effects play out over the surface of the earth it is useful to describe briefly the process by which the results depicted in the figures are derived. They start with global (or general) circulation models (GCMs) that model the physics and chemistry of the atmosphere and its interactions with oceans and the land surface. Several GCMs have been developed independently around the world. Next, integrated assessment models (IAMs) simulate the interactions between humans and their surroundings, including industrial activities, transportation, agriculture and other land uses and estimate the emissions of the various greenhouse gases (carbon dioxide, methane and nitrous oxide are the most important). Several independent IAMs exist as well. The emissions simulation results of the IAMs are made available to the GCM models as inputs that alter atmospheric chemistry. The end result is a set of estimates of precipitation and temperature values around the globe often at 2 degree intervals (about 200 km at the equator) for most models. Periodically, the IPCC issues assessment reports on the state of our understanding of climate science and interactions with the oceans, land and human activities. Figure 1 shows changes in average precipitation globally between 2000 and 2050 for four GCMs, each using the A1B scenario.

Figure 2 shows the change in average maximum temperature. A quick glance at these figures shows that substantial differences exist between models, particularly at regional scale. For example, in Figure 1 the CNRM-CM3 GCM predicts that Southern Africa will be wetter, while the other models have the same region getting drier. In South Africa, the CNRM-CM3 GCM has an increase in precipitation, while the CSIRO GCM, MIROC GCM and CSIRO-MK3 have a drier South Africa. In Figure 2, we see that all GCMs predict large temperature increases for South Africa. These figures illustrate qualitatively the range of potential climate outcomes using current modeling capabilities and provide an indication of the uncertainty in climate-change impacts. Policymakers are not yet in a position to select specific solutions for specific locations – unless there is significant agreement between models. Rather, it is important to note general trends and to consider policies that are helpful and robust across the range of climate outcomes.

3 Agriculture, Food Security and South African Development

South Africa continues to have a significant portion of its population under- or malnourished (Department of Health 2008). While poor nutrition was previously largely found in rural areas (Department of Agriculture 2002); of late there has been an increase of food insecurity and malnourishment in urban areas (Frayne et al. 2009) as a consequence of rural to urban migration and unemployment. This is despite significant investments in agricultural production activities. The small-scale farming sector makes a limited contribution to the agriculture component of the economy, despite research showing the value of investments in the small-scale agriculture elsewhere in the world (Cousins 2010).

Food insecurity in southern Africa is exacerbated by the negative impacts of HIV-AIDS on the ability of the active population to produce food. South Africa has an HIV rate of about 16%, reaching 29% among the 20–49 year age group (Statistics South Africa 2012; Ruben et al. 1998).

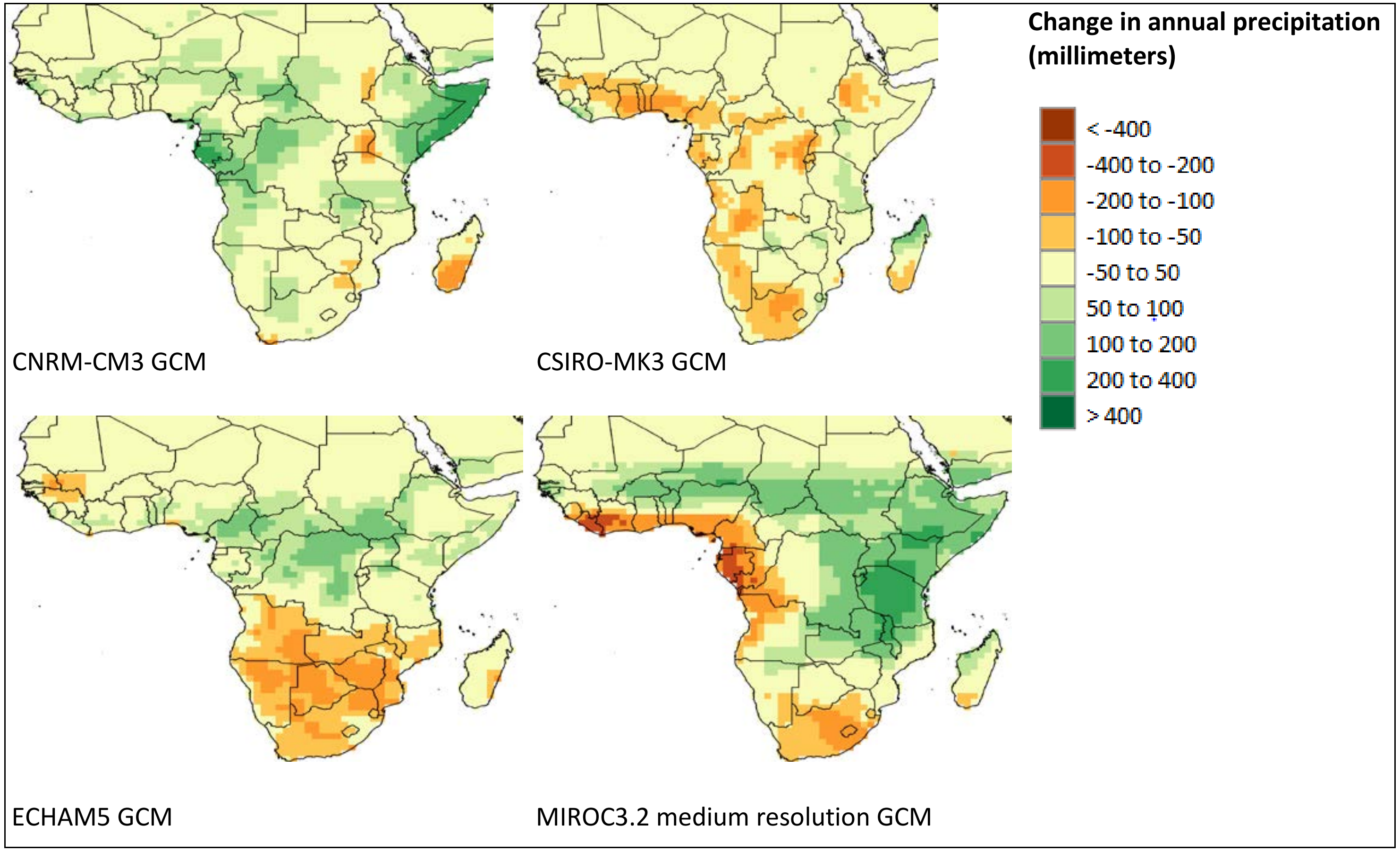


Figure 1. Changes in mean annual precipitation between 2000 and 2050 using the A1B scenario (mm per year). Source: IFPRI calculations based on downscaled climate data available at http://ccafs-climate.org.

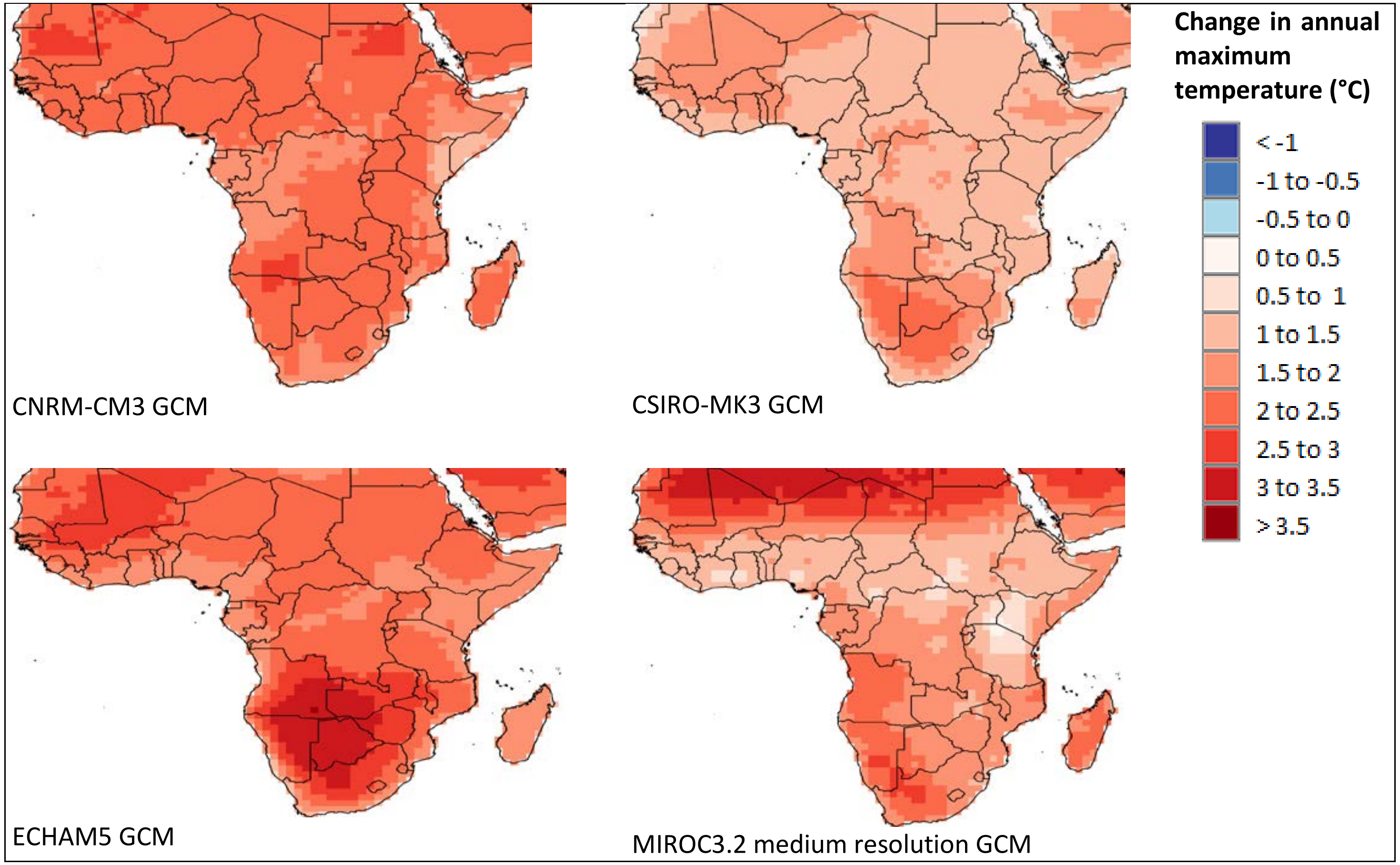


Figure 2. Changes in annual maximum temperature between 2000 and 2050 using the A1B scenario (°C). Source: IFPRI calculations based on downscaled climate data available at http://ccafs-climate.org/.

Government is revitalizing irrigation schemes and training agriculture personnel with emphasis to support of small-scale agriculture producers and home gardening to improve household food security (Fanadzo 2012). There is also concerted effort to improve marketing and value addition.

3.1 Review of the Current Situation

A selection of key statistics is presented in this section highlighting some of the important changes in the South African economy on the last quarter of the 20th century and the beginning of the 21st century.

3.1.1 Population

South Africa continues to produce food largely for direct human consumption. In the livestock sector, despite being a large producer, South Africa is a net importer of products such as meat and milk (Statistics South Africa 2008). Population, therefore, remains a key determinant of the demand for food. The increase in population particularly in the urban areas has resulted in an increase in food demand. Figure 3 shows total and rural population and counts (left axis) and the share of urban population (right axis). The most striking observation is the drastic increase in population from about 1985, particularly the urban population. This population growth has continued to increase as the rural areas continue to be unattractive to job seekers. The post-1994 population increase is more likely to be due to immigration from other African countries ravaged by wars and economic decline. This continued growth means an increase in food demand in the coming years because the urban food preferences and sources differ from those in rural areas.

Table 1 provides additional information on rates of population growth.

Figure 4 shows the geographic distribution of population within South Africa, based on census data and other sources. It is clear from the figure that there is, generally, heavy concentration of South African population in urban centers and on the eastern, wetter, side. This distribution of the population means that the urban centers need food management strategies that link well with areas of food production. It further implies that the cost of food may

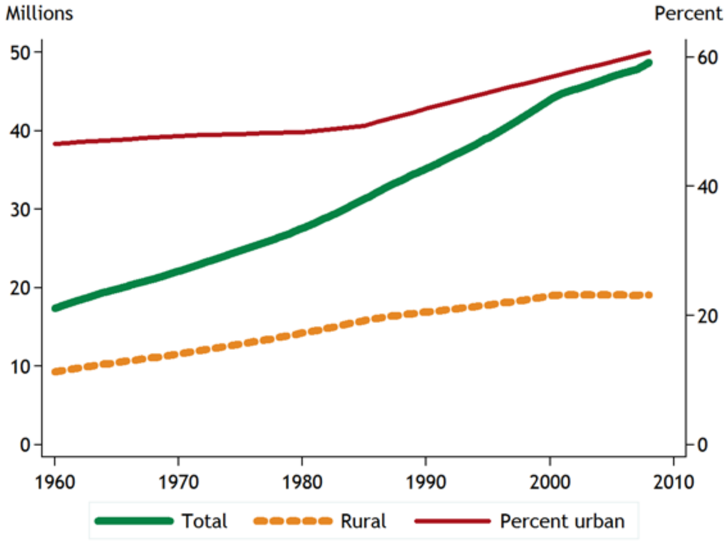


Figure 3. Population trends: Total population, rural population, and percent urban, 1960–2008. Source: World Bank (2009).

Table 1. Population Growth Rates, 1960–2008 (%)

Decade	Total Growth Rate	Rural Growth Rate	Urban Growth Rate
1960-1969	0.02	0.02	0.02
1970-1979	0.02	0.02	0.02
1980-1989	0.03	0.02	0.03
1990-1999	0.02	0.01	0.00
2000-2008	0.01	0.00	0.02

Source: IFPRI calculations, based on World Bank (2009).

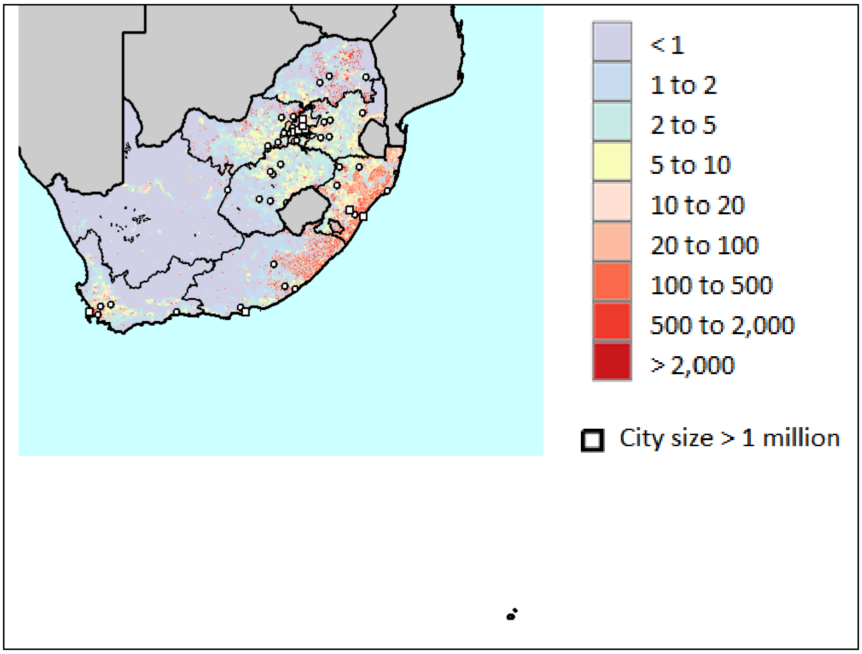


Figure 4. Population distribution (persons per square kilometer). Source: IFPRI estimates from GRUMP for 2000. Center for International Earth Science Information Network Columbia University (2004).

increase as a result of the increased distances between sources of production and areas of demand. The arid parts of the Eastern Cape, Western Cape and Northern Cape, Free State, North West and Limpopo provinces remain largely sparsely populated.

Figure 5 shows population projections by the UN Population office through 2050. It is clear that by most projections the population of South Africa will continue to increase through 2050.

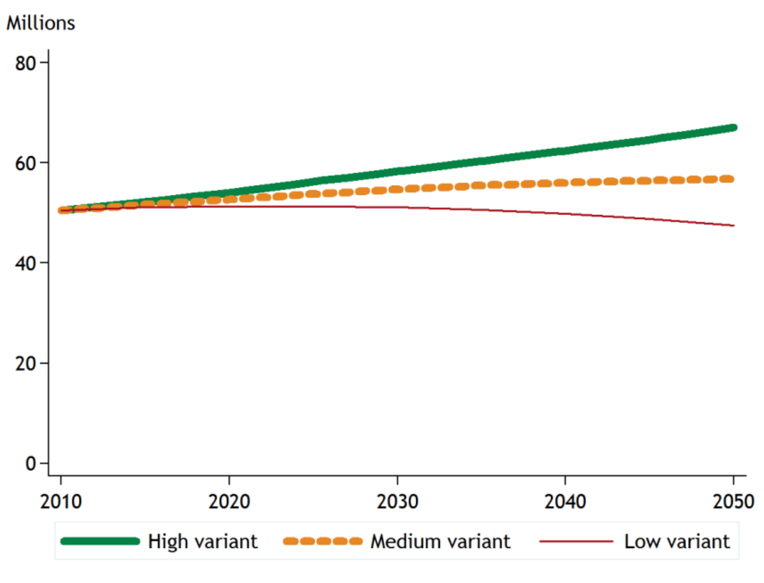


Figure 5. Population scenarios for 2010 to 2050.
Source: United Nations (2008).

3.1.2 Income

The income available to an individual is the single best indicator of their resilience to stresses. Figure 6 shows trends in GDP per capita and proportion of GDP from agriculture. The agricultural share is included both because of its vulnerability to climate change impacts as well as an indicator of the level of development of the country. As development increases, the importance of agriculture in GDP tends to decline. South Africa is considered to be an industry-based economy. This is clear from Figure 6, where despite an increase in *per capita* GDP since the late 1960s the contribution of agriculture to the GDP has declined drastically. In 1970 agriculture's share of GDP (excluding downstream activities such as food processing and retail) was about 8%, but by 2010 it was only about 3%.

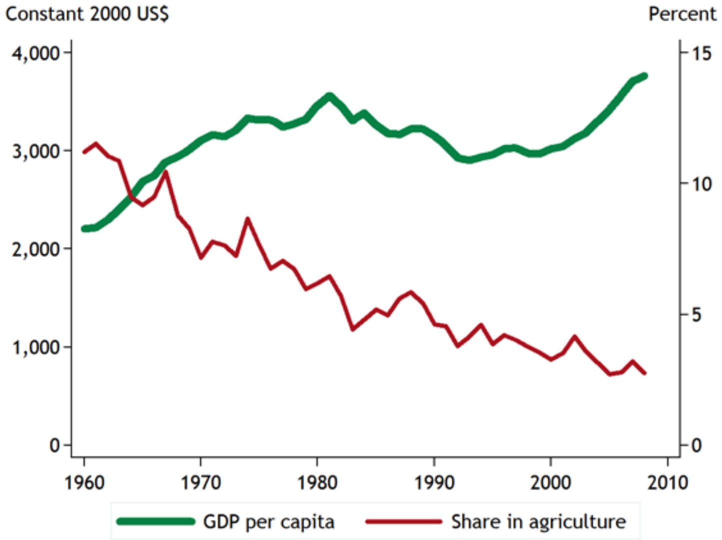


Figure 6. Per capita GDP (constant 2000 US$) and share of GDP from agriculture. Source: World Bank (2009).

3.1.3 Vulnerability

Vulnerability is the lack of ability to recover from a stress. Poor people are vulnerable to many different kinds of stresses because they lack the financial resources to respond. In agriculture, poor people are particularly vulnerable to the stresses of an uncertain climate. In this article the focus is on income, both level and sources. At the national level, vulnerability arises in the interactions among population and income growth and the availability of natural and manufactured resources. National per capita income statistics reported above potentially conceal large variations across sectors or regions and within the sampled populations.

Although the economy of South Africa has grown in the past decades it has, to a large extent, failed to create decent jobs that could assist in reducing the fraction of the population that is below the poverty line. Figure 7 shows the distribution of the proportion of the population living on less than US$2.00 per day. The regional disparities become apparent. Clearly except for the Western Cape and Gauteng and parts of North West, Limpopo, KwaZulu-Natal and Mpumalanga, between 50 and 80 % of the inhabitants in less-urbanized and industrialized areas live on less than US$2 per day.

Table 2 provides some data on additional indicators of vulnerability and resilience to economic shocks: the education level of the population, literacy, and concentration of labor in poorer or less dynamic sectors. Literacy rate in South Africa is high and the share of people employed in agriculture is low.

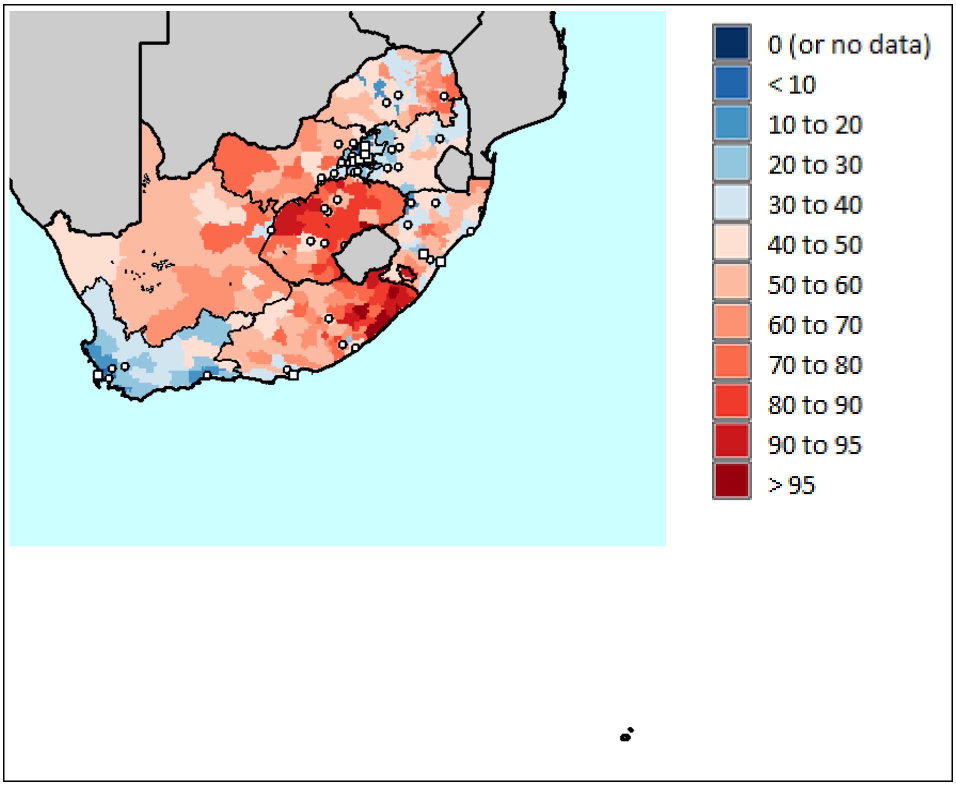


Figure 7. Poverty (percent below US$2 per day).
Source: Wood et al. (2010) available at labs.harvestchoice.org/2010/08/poverty-maps.

Table 2. Education and labor statistics

Indicator	Year	Value
Primary school enrollment: Percent gross (3-year average)	2007	102.5
Secondary school enrollment: Percent gross (3-year average)	2007	97.1
Adult literacy rate	2007	88
Percent employed in agriculture	2007	8.8

Source: World Bank (2009).

The outcomes of significant vulnerability include low life expectancy and high infant mortality. Figure 8 shows two non-economic correlates of poverty, life expectancy at birth and under-5 mortality. The life expectancy at birth for South Africans has decreased significantly to pre-1980 levels of about 50 years, largely due to HIV-AIDS. On the other hand, there has been a decrease in under-5 mortality rate from over 100 babies per 1,000 to below 60 babies per 1,000.

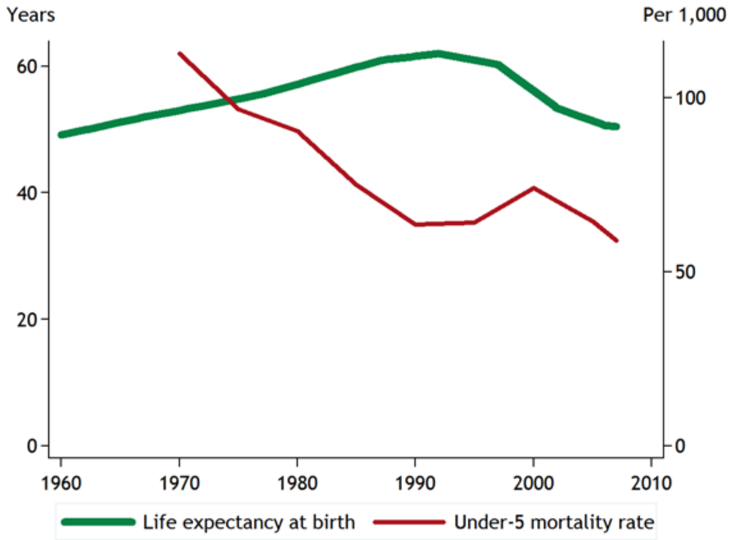


Figure 8. Well-being indicators: Life expectancy at birth and under-5 mortality rate. Source: World Bank (2009).

3.2 Review of Land Use and Agriculture

Agricultural production is dependent on the availability of land that has sufficient water, soil resources and an adequate growing season. As shown in Figure 9 South Africa's resources are varied. Only a small portion (12%) of the total area of South Africa is suitable for crop production, concentrated in the east and central parts of the country (MacVicar 1974). Livestock farming (including game), is the main agricultural activity in the more arid areas for most of South Africa. There are important areas for wheat and fruit production in the Western Cape and Northern provinces, often under irrigation.

Figure 10 shows the locations of protected areas, including parks and reserves. These locations, besides protecting biodiversity and water resources,

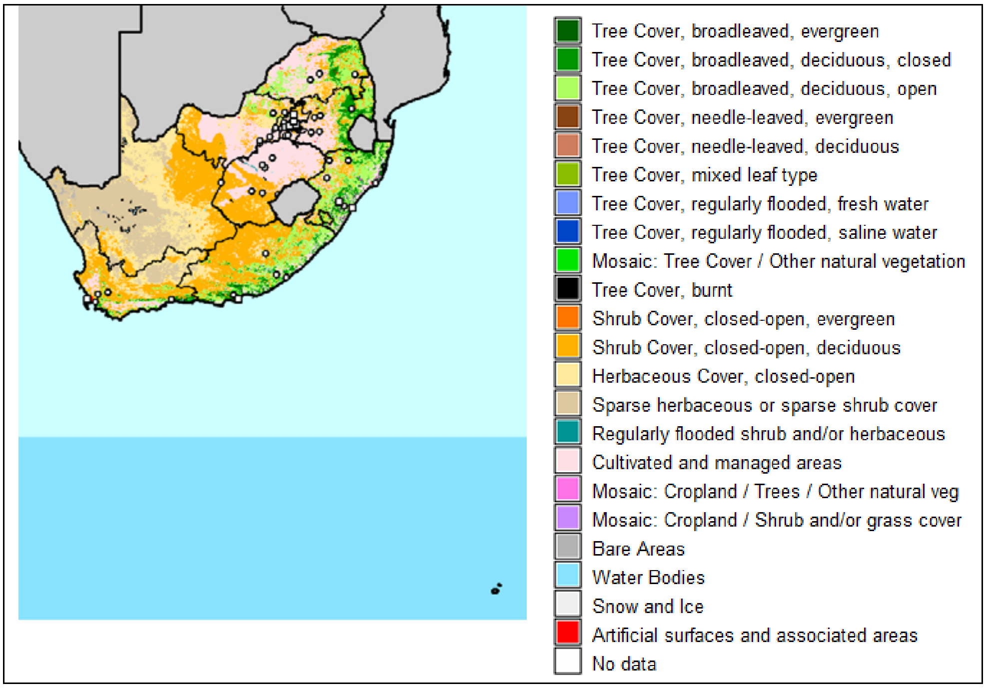


Figure 9. Land cover in 2000. Source: GLC2000 (JRC 2000).

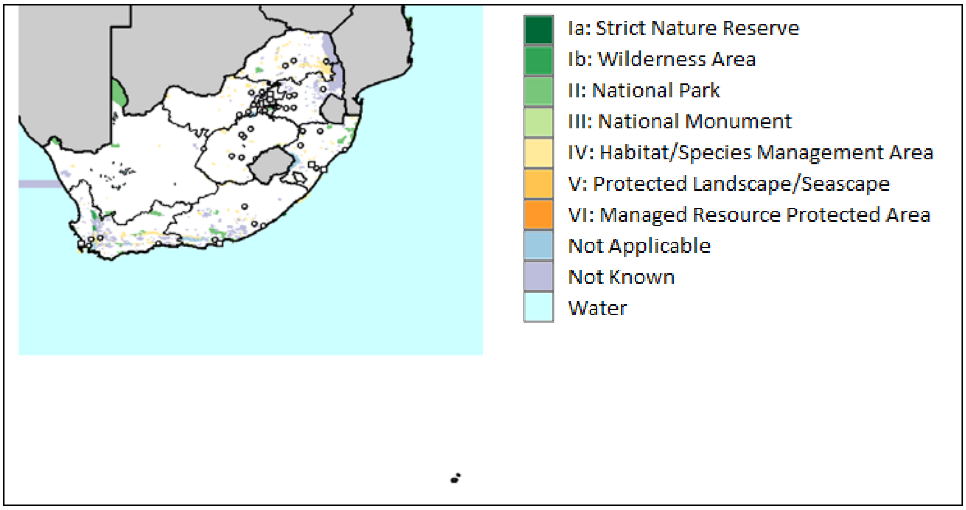


Figure 10. Protected areas in 2000 (Source: UNEP 2009). Water is from Global Lakes and Wetlands Database (WWF) (Lehner and Döll 2004).

are also important for the tourism industry, which at 8% of the GDP exceeds agriculture. Not shown is the area under private or communal wildlife-based management, estimated to be about twice the terrestrial area under state protection.

Figure 11 shows travel time maps to the larger cities, which provide potential markets for agricultural products. Policy makers need to keep in mind the importance of transport costs when considering potential for agricultural expansion; that is, if fertile but unused land is far from markets, it represents potential land for expansion only if transportation infrastructure is put in place, and if the land does not conflict with conservation priorities seen in Figure 10. South Africa has a dense road network, thus travel time to major urban areas is generally low. This provides significant opportunity for the expansion of food supply industries. Travel time to cities with over 25,000 people is generally short. Movements of goods to major urban centers, particularly in the food producing areas of the east, central and northern parts of the country, make it feasible to develop an agriculture value chain that is

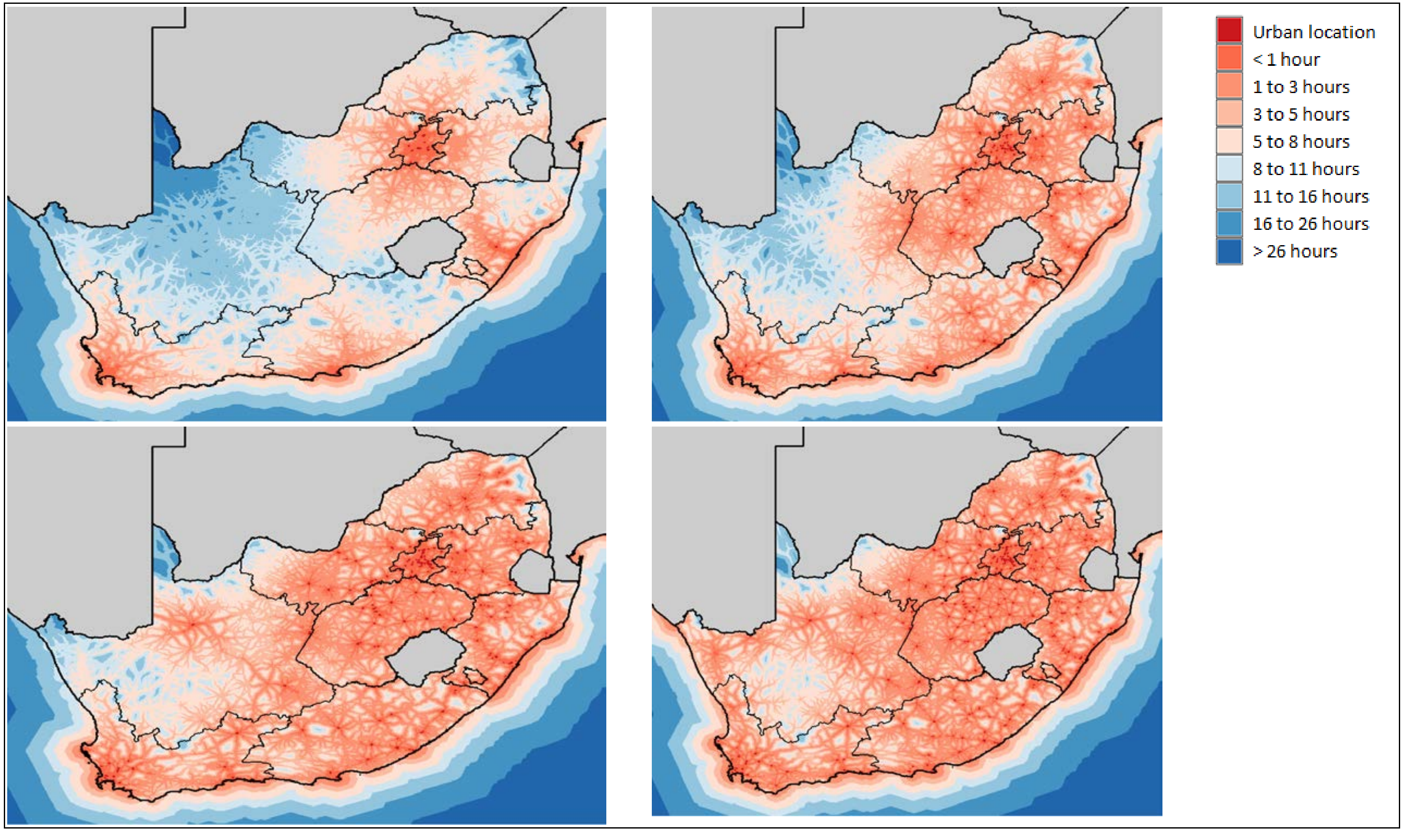


Figure 11. Travel time to urban areas in 2000. Source: Authors, based on several input layers, including CIESIN population points and World Gazetteer (Helders 2005). Notes: The first map is travel time to cities of 500,000 or more people; the second map is travel time to cities of 100,000 or more; the third map is travel time to towns and cities of 50,000 or more; and fourth map is travel time to towns and cities of 25,000 or more people.

viable and can assist in meeting the demands for food. South Africa has a very strong air transportation and ports system that further provides opportunities in international trade.

3.3 Agriculture Overview

Tables 3 to 5 show key agricultural commodities in terms of area harvested, value of the harvest, and food for people (this last item was ranked by weight) for the period 2006–2008. South Africa has about 22% of its land suitable for arable agriculture with only 12% considered as prime agricultural land (MacVicar, 1974). The rest of the country is suitable for extensive livestock and wildlife. Maize, wheat, sunflower and sugarcane occupy about 75% of the total harvested area of about 5.2 million hectares with maize contributing almost half of this area. Grapes top the list by value, accounting for 25% compared to maize's 17% contribution, and followed by sugarcane, wheat and potatoes.

Maize (21%) and wheat (11.5%) are the most consumed food commodities with beer (11.0%) at third place (Table 5). In general the large grains and cereals remain important food commodities in the South African agriculture sector. South Africa remains the largest maize producer in the SADC region.

Figure 12 to Figure 17 show the estimated yield and growing areas for key crops, maize, wheat, sugarcane and soybeans. These figures are based on the SPAM data set (You et al. 2009), a plausible allocation of national and subnational data on crop area and yields. Water availability remains a major obstacle to the expansion of agriculture. Almost 50% of South Africa's water is used for agriculture with about 1.3 million hectares under irrigation.

Table 3. Harvest area of leading agricultural commodities, average of 2006–2008

Rank	Crop	% of total	Area harvested (1,000 hectares)
1	Maize	47.5	2,461
2	Wheat	13.8	717
3	Sunflower seed	8.7	451
4	Sugar cane	8.1	422
5	Soybeans	3.8	199
6	Grapes	2.3	119
7	Barley	1.5	78
8	Sorghum	1.3	65
9	Potatoes	1.1	58
10	Beans, dry	1.0	50
	Total	100.0	5,185

Source: FAO (2010).

Table 4. Value of production for leading agricultural commodities, average of 2006–2008

Rank	Crop	% of total	Value of Production (million US$)
1	Grapes	25.3	1,741
2	Maize	17.6	1,216.
3	Sugar cane	8.5	584
4	Wheat	7.0	486
5	Potatoes	6.5	451
6	Oranges	4.5	307
7	Apples	3.8	262
8	Maize, green	3.1	211
9	Sunflower seed	2.0	135
10	Tomatoes	1.9	128
	Total	100.0	6,890

Source: FAO (2010).

Table 5. Consumption of leading food commodities by mass, average of 2003–2006

Rank	Crop	% of total	Food consumption (1,000 mt)
1	Maize	21.8	4,952
2	Wheat	11.5	2,615
3	Beer	11.0	2,508
4	Sugar (Raw Equivalent)	6.6	1,510
5	Potatoes	5.8	1,318
6	Vegetables, Other	5.5	1,258
7	Poultry Meat	4.7	1,074
8	Rice (Milled Equivalent)	3.3	747
9	Beverages, Fermented	3.3	747
	Total	100.0	22,748

Source: FAO (2010).

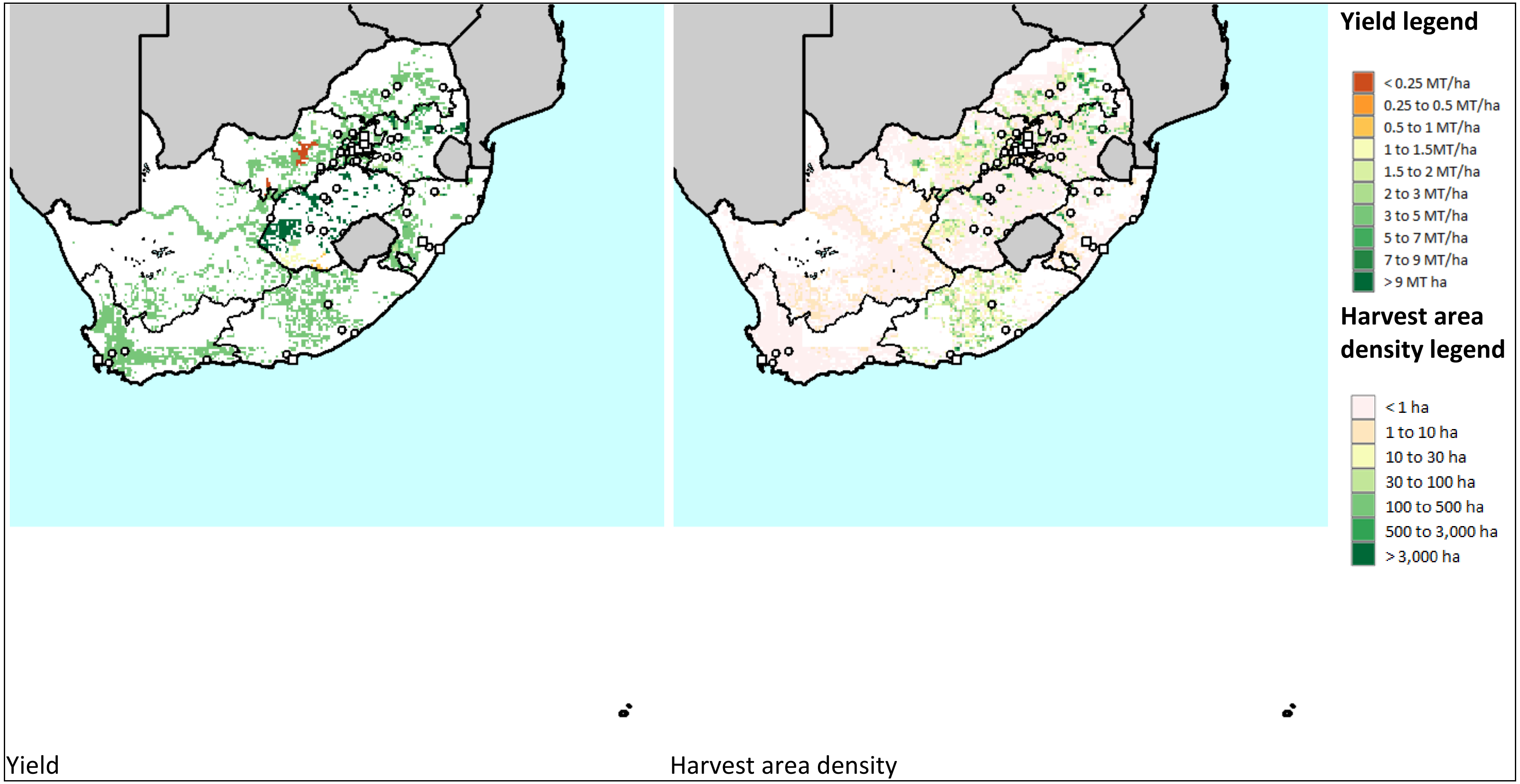


Figure 12. Yield and harvest area density for main crops: irrigated maize in 2000. Source: SPAM Dataset (You et al. 2009).

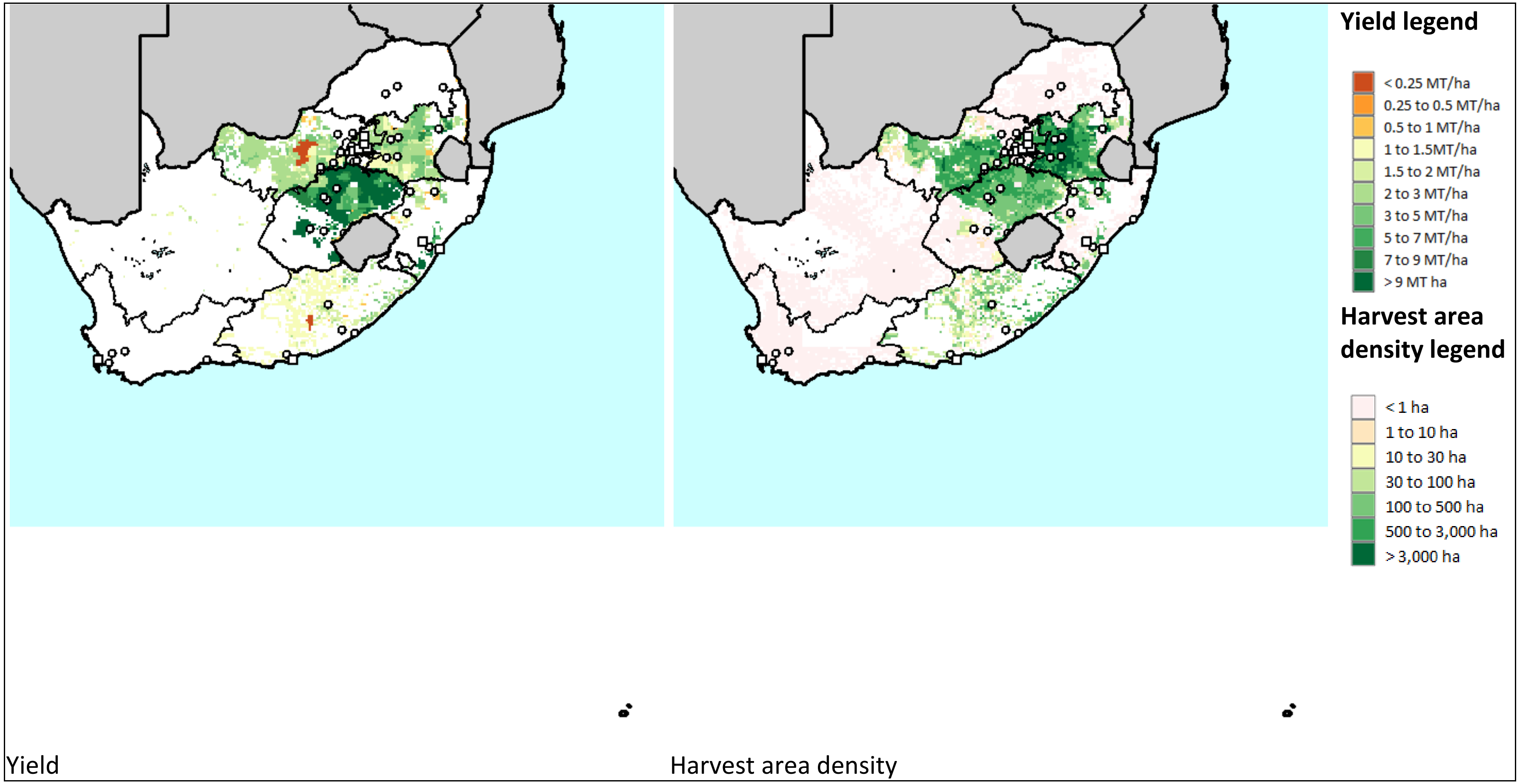


Figure 13. Yield and harvest area density for main crops: rainfed maize in 2000. Source: SPAM Dataset (You et al. 2009).

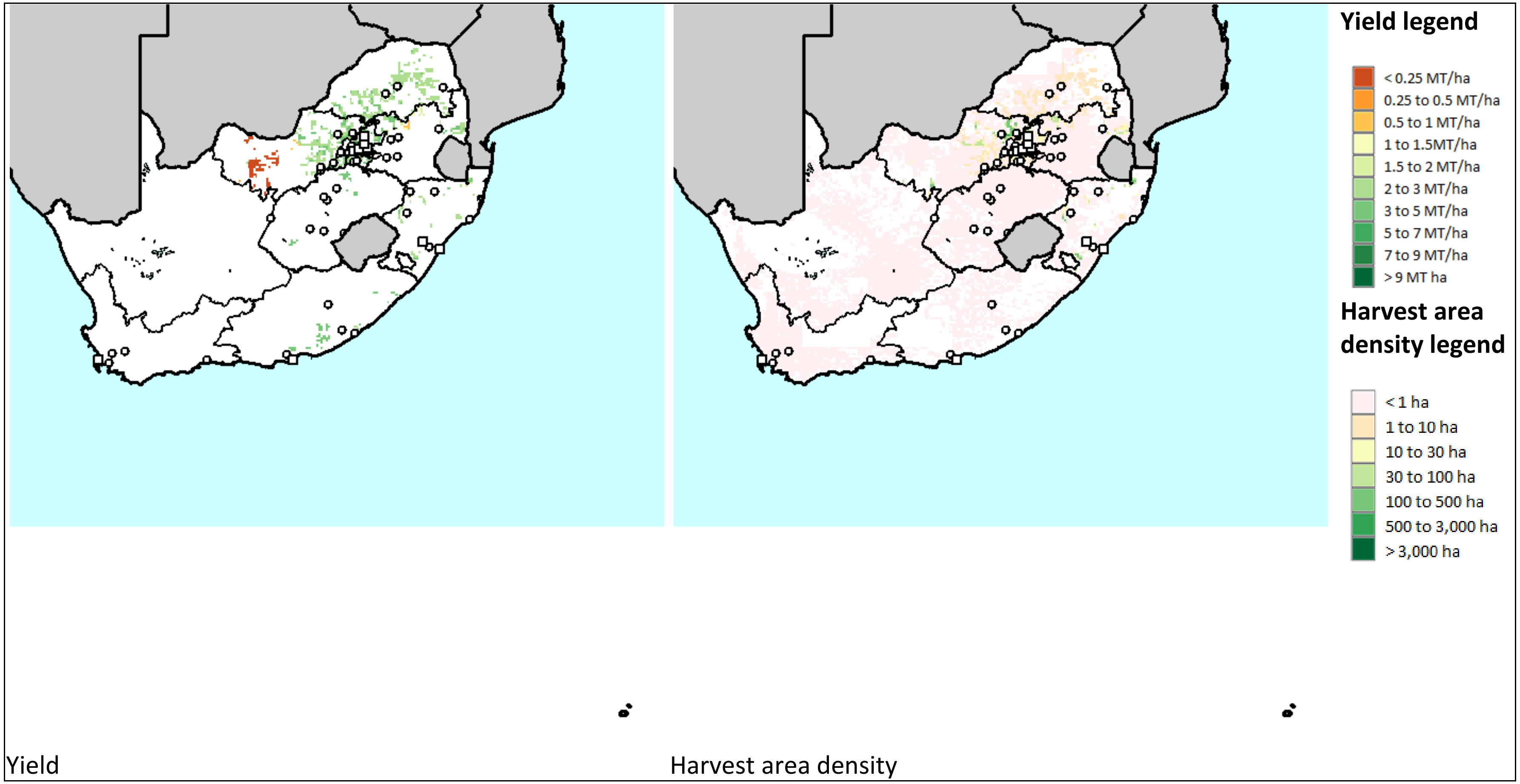


Figure 14. Yield and harvest area density for main crops: irrigated groundnuts in 2000. Source: SPAM Dataset (You et al. 2009).

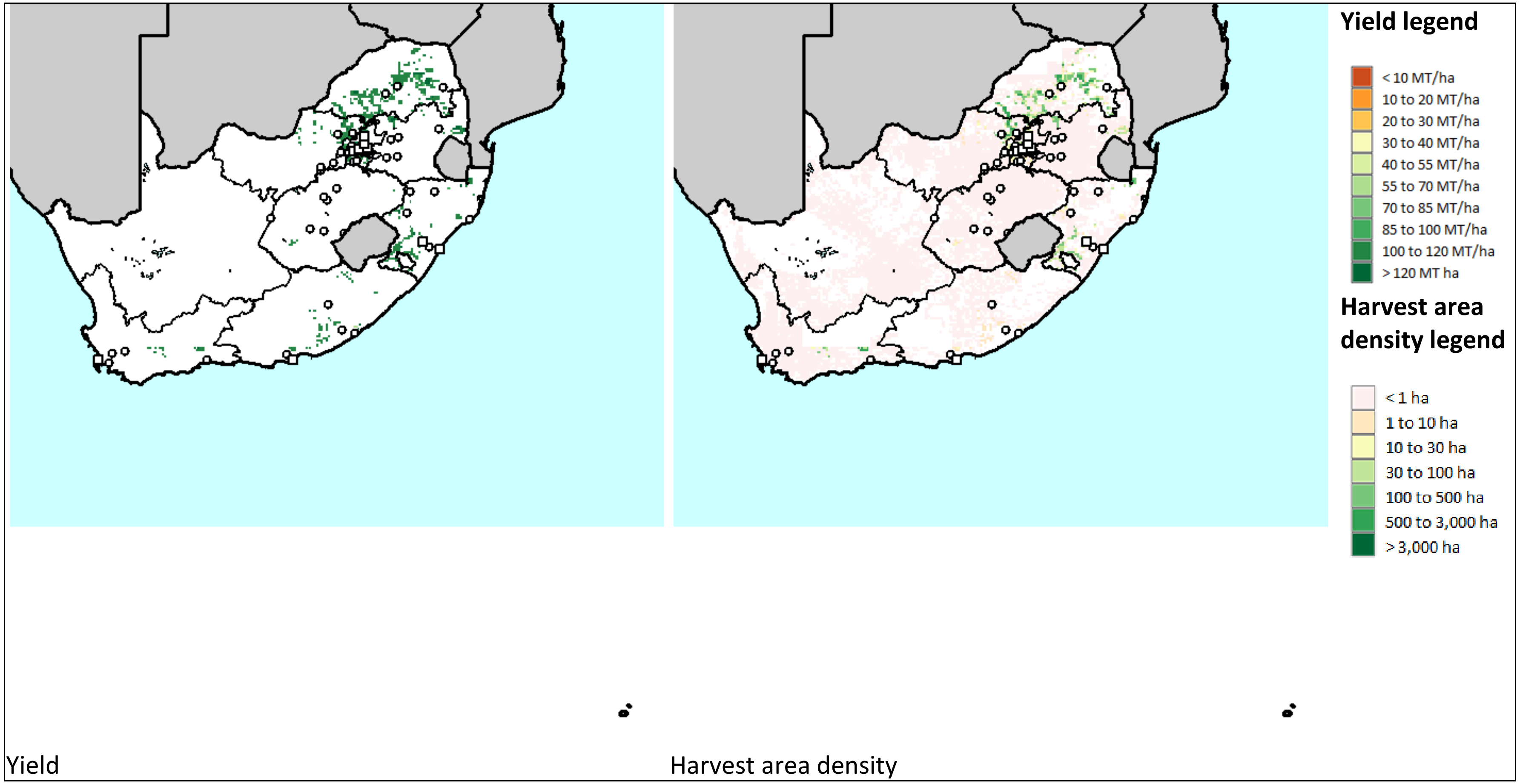


Figure 15. Yield and *harvest* area density for main crops: irrigated sugarcane in 2000. Source: SPAM Dataset (You et al. 2009).

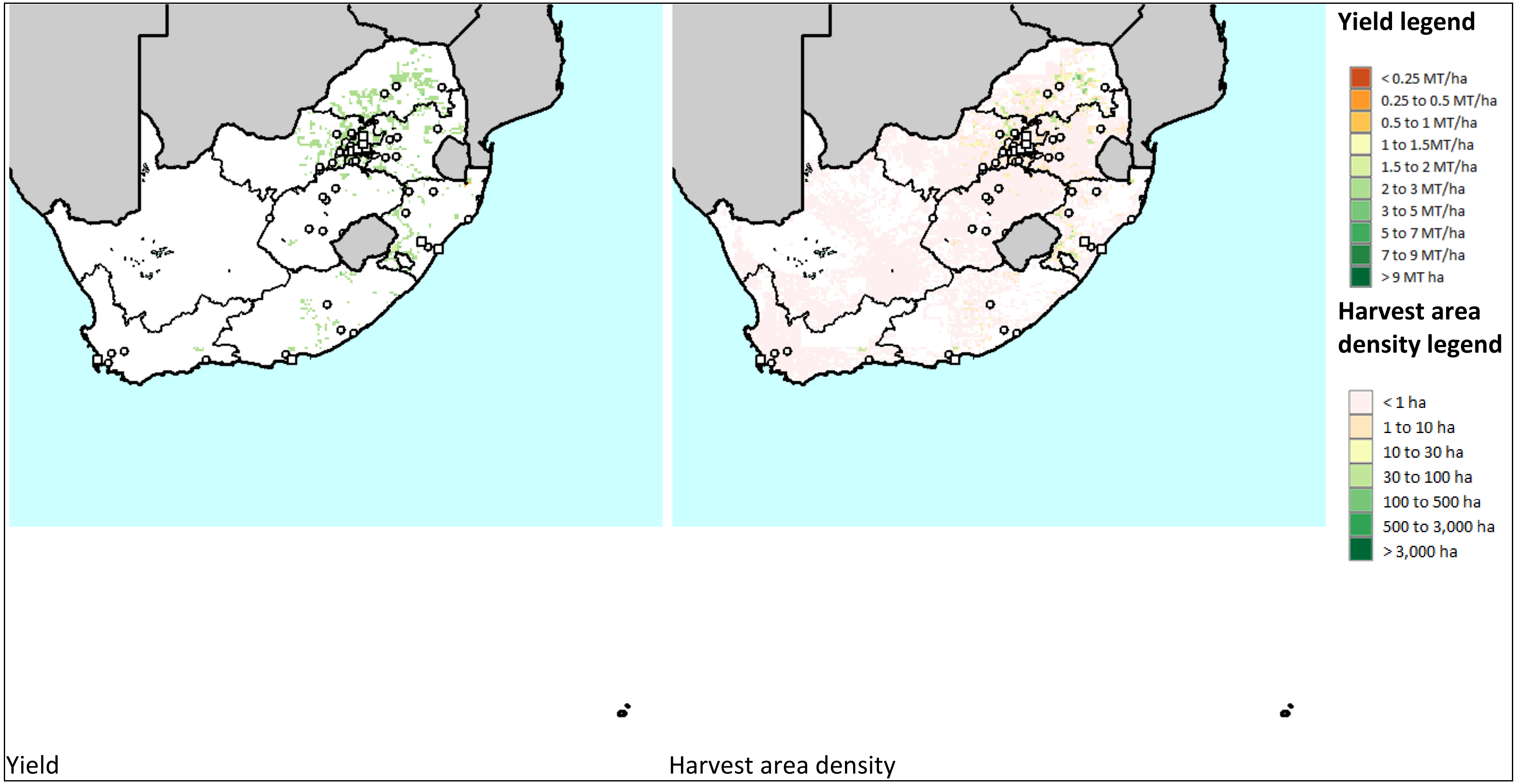


*Figure 16***.** Yield and harvest area density for main crops: irrigated soybeans in 2000. Source: SPAM Dataset (You et al. 2009).

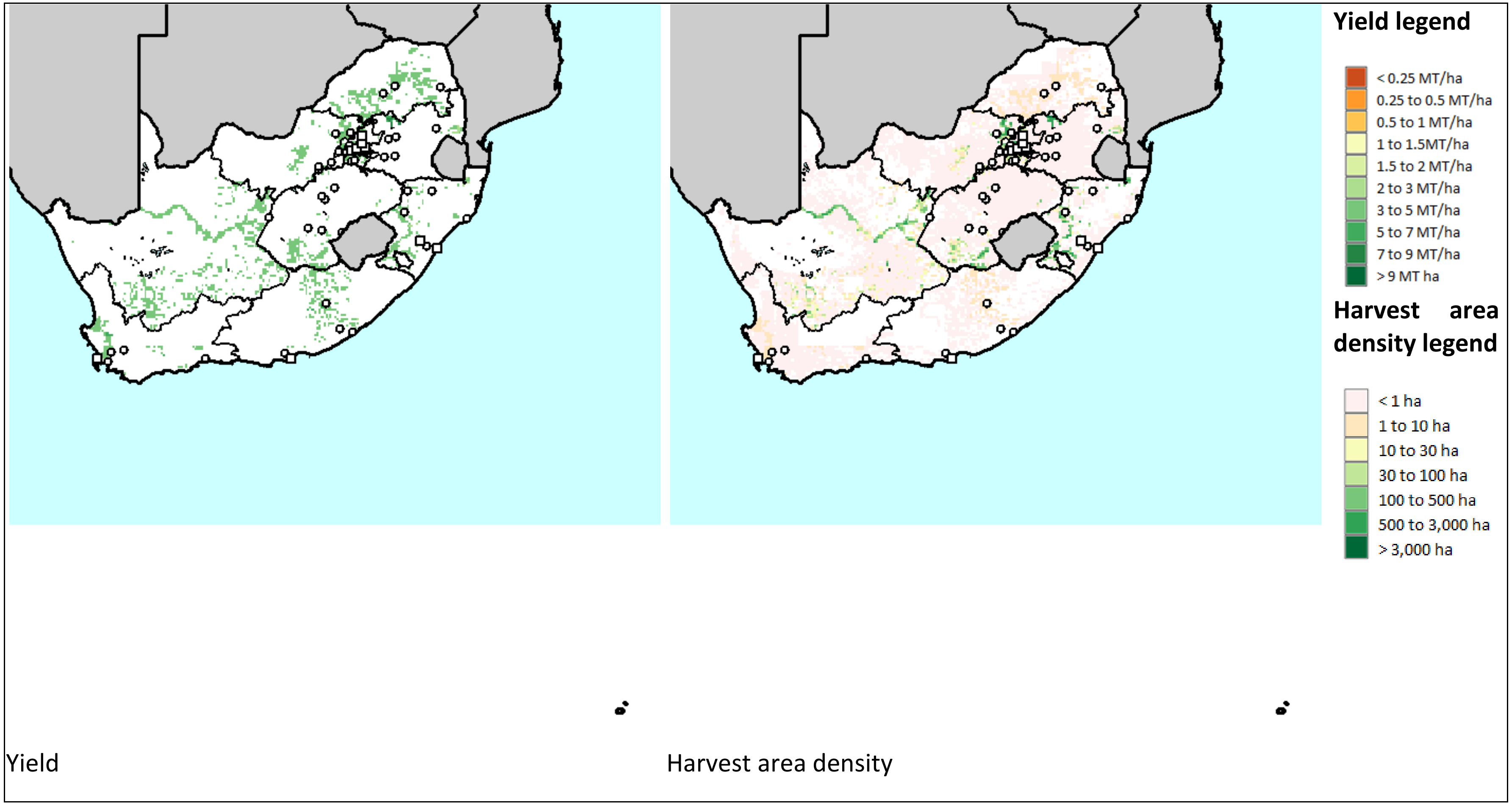


*Figure 17***.** Yield and harvest area density for main crops: irrigated wheat in 2000. Source: SPAM Dataset (You et al. 2009).

4 Scenarios for Adaptation

To better understand the potential impact of climate change on South Africa's food security a scenario's approach is used. The Millennium Ecosystem Assessment's Ecosystems and Human Well-being: Scenarios, Volume 2, Chapter 2 provides a useful definition:

> "Scenarios are plausible, challenging, and relevant stories about how the future might unfold, which can be told in both words and numbers. Scenarios are not forecasts, projections, predictions, or recommendations. They are about envisioning future pathways and accounting for critical uncertainties" (Raskin et al. 2005).

For this report, combinations of economic and demographic drivers have been selected that collectively result in three pathways – a baseline scenario that is "middle of the road", a pessimistic scenario that chooses driver combinations that, while plausible, are likely to result in more negative outcomes for human well-being, and an optimistic scenario that is likely to result in improved outcomes relative to the baseline. These three overall scenarios are further qualified by four climate scenarios: plausible changes in climate conditions based on scenarios of greenhouse gas emissions.

4.1 Biophysical Scenarios

This section presents the climate scenarios used in the analysis and the crop physiological response to the changes in climate between 2000 and 2050.

4.1.1 Climate Scenarios

Table 6 shows global summary statistics for the selected GCMS and SRES scenarios from the IPCC4th assessment that make available average monthly minimum and maximum temperature, sorted from lowest to highest precipitation change. It also included the mean temperature and precipitation change for the complete ensemble of the GCMs reported by the IPCC4th assessment.[1] It is clear from Table 6 that there are general tendencies but also a large degree of uncertainty. At a global scale temperature rises as does annual precipitation. A 1°C increase in average temperature results in less than 1% increase in precipitation. Temperature increases of over 2°C result in 2–5% increase in precipitation; but the evaporative demand rises by a similar amount. Secondly, with identical GHG emissions, the GCM climate outputs differ substantially. The most extreme comparison is with the outcomes of the B1 scenario. The CSIRO GCM has almost no increase in average annual precipitation and the smallest temperature increase of the GCM/GHG scenario combinations. The MIROC GCM has the second largest increase in precipitation (with scenario B1) and one of the largest increases in average temperature.

For scenario analysis, four climate scenarios that span a range of the GCM ensemble results were used. These also have the requisite monthly average minimum and maximum temperature data needed for the crop modeling analysis. The CSIRO A1B and B1 scenarios represent a dry and relatively cool future; the MIROC A1B and B1 scenarios represent a wet and warmer future.

Note: In Table 6 and elsewhere in the text, reference to a particular year for the climate realization such as 2000, 2050 is in fact a reference to mean values for the two decades around the year; for example the data described as 2050 are representative of the period 2041–2060. The data for the reference period labeled “2000” in the table are for the period 1950–2000. GCM-scenario combinations in bold are the ones used in the analysis.

Figure 18 shows precipitation changes and Figure 19 shows temperature changes for South Africa under 4 downscaled climate models (CNRM, CSIRO, ECHAM, and MIROC) with the A1B scenario. It is important to understand that the analysis and results of the climate scenarios include only changes in means temperature and precipitation. It does not include any measures of variability. As climate change is likely to lead to more extreme events that would have negative effects on agriculture, such as droughts, the results reported here are underestimates of likely negative effects of climate

[1] For maps showing the individual GCM results and the ensemble means see: www.ipcc.ch/publications_and_data/ar4/wg1/en/suppl/chapter10/Ch10_indivi-maps.html.

change. Except for the CNRM, in general, all the other 3 GCM predict a negative change in precipitation for South Africa with the A1B scenario. The CRNM model predicts a slight increase in precipitation for the Northern and Eastern Cape regions of the country.

Figure 19 shows changes in maximum temperature for the month with the highest mean daily maximum temperature. All the models predict an increase in normal annual maximum temperatures for South Africa with the major part of the country receiving temperature increases in the region of 1 to 2°C by 2050.

*Table 6***.** GCM and SRES scenario global average changes, 2000–2050

GCM	SRES scenario	Change between 2000 and 2050 in the annual averages			
		Precip (%)	Precip (mm)	MinTemp (°C)	MaxTemp (°C)
CSIRO	**B1**	**0.0**	**0.1**	**1.2**	**1.0**
CSIRO	**A1B**	**0.7**	**4.8**	**1.6**	**1.4**
CSIRO	A2	0.9	6.5	1.9	1.8
ECH	B1	1.6	11.6	2.1	1.9
CNR	B1	1.9	14.0	1.9	1.7
ECH	A2	2.1	15.0	2.4	2.2
CNR	A2	2.7	19.5	2.5	2.2
ECH	A1B	3.2	23.4	2.7	2.5
MIROC	A2	3.2	23.4	2.8	2.6
CNR	A1B	3.3	23.8	2.6	2.3
MIROC	**B1**	**3.6**	**25.7**	**2.4**	**2.3**
MIROC	**A1B**	**4.7**	**33.8**	**3.0**	**2.8**
Multi-model ensemble mean					
	A1B	1.5		1.8	
	A2	1.3		1.7	
	B1	1.7		1.3	

Source: Authors' calculations. Multi-model ensemble means come from Boko et al. (2007): mean temperature increase, Table 10.5, and mean precipitation increase, Table S10.2. See Appendix 3 for details on the GCMs and scenarios.

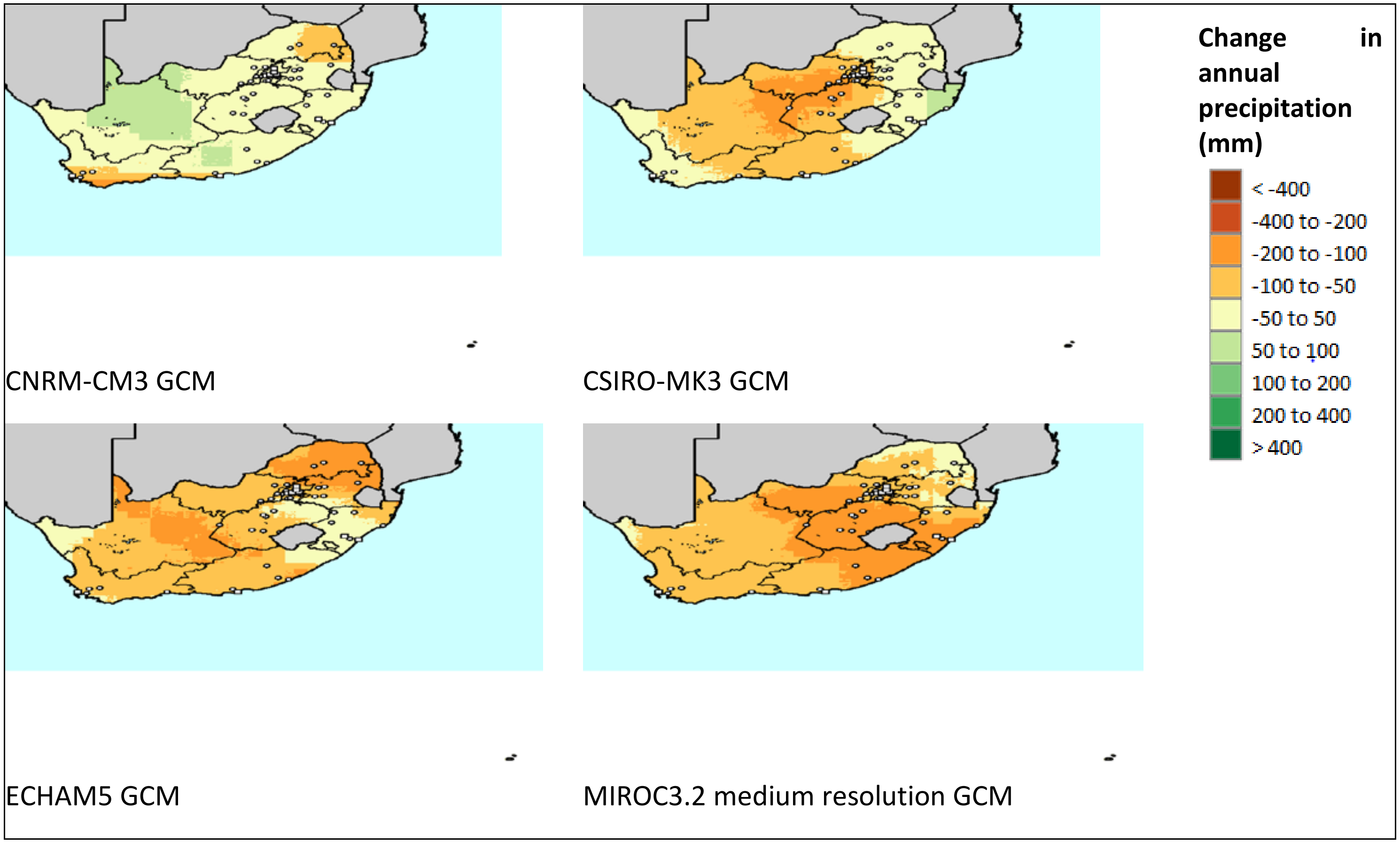


Figure 18. Changes in mean annual precipitation for South Africa between 2000 and 2050 using the A1B scenario (millimeters). Source: IFPRI calculations based on downscaled climate data available at http://ccafs-climate.org/.

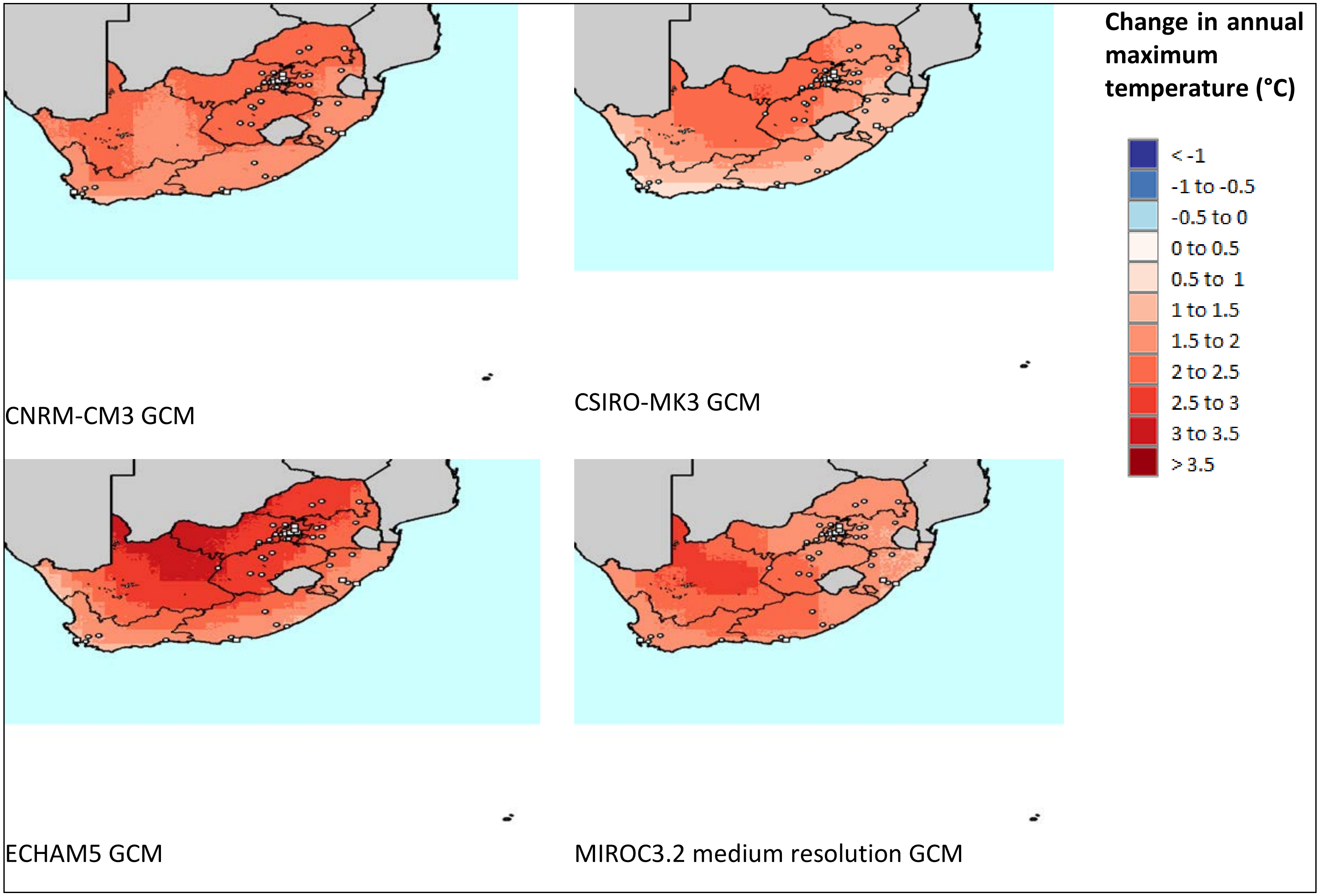


Figure 19. Changes in normal annual maximum temperature for South Africa between 2000 and 2050 using the A1B scenario (°C). Source: IFPRI calculations based on downscaled climate data available at http://ccafs-climate.org/.

4.1.2 Crop Physiological Response to Climate Change

The DSSAT crop modeling system (Jones et al. 2003) is used to simulate responses of five important crops (rice, wheat, maize, soybeans, and groundnuts) to climate, soil, and nutrient availability, at current locations based on the SPAM dataset of crop location and management techniques (You and Wood 2006). In addition to temperature and precipitation, we also input soil data, assumptions about fertilizer use and planting month, and additional climate data such as days of sunlight each month.

We then repeated the exercise for each of the 4 future scenarios for the year 2050. For all locations, variety, soil and management practices were held constant. We then compared the future yield results from DSSAT to the current or baseline yield results from DSSAT.

The results for maize, wheat, sugarcane, groundnuts and soybean for South Africa are reported on. These results are mapped in Figure 20 to Figure 25. The comparison is between crop yields for 2050 with climate change scenarios with those for 2000 climate conditions. For irrigated crops, climate change effects modeled in DSSAT are purely from temperature as sufficient water is assumed in the modeling. Water stress in irrigated crops is brought in through the water model component of the IMPACT model suite, which incorporates climate change effects on water availability. For South Africa, in basins where major coal powered thermal power stations are being commissioned, a 2% reduction in irrigation water was imposed.

In general, a review of results in Figure 20 to Figure 25 reveals that the average direct yield effects from climate change are relatively small. Except for rainfed maize where there are gains between 5 and 25% predicted, and gain in rainfed groundnuts; the other crops show minor changes in average yield. From a protein food security perspective, the projected increase in rainfed groundnut production is interesting, although groundnuts are currently a relatively minor crop in South Africa.

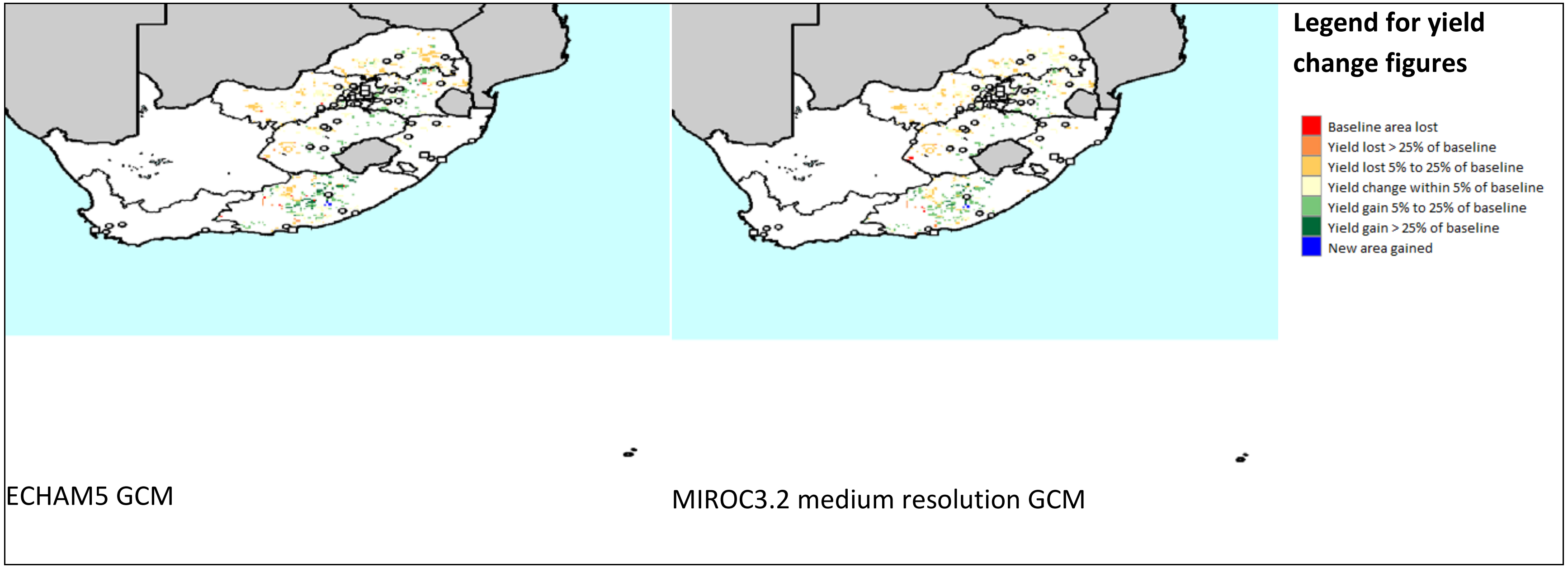


Figure 20. Yield change map under climate change scenarios: irrigated maize. Source: IFPRI calculations based on downscaled climate data and DSSAT model runs.

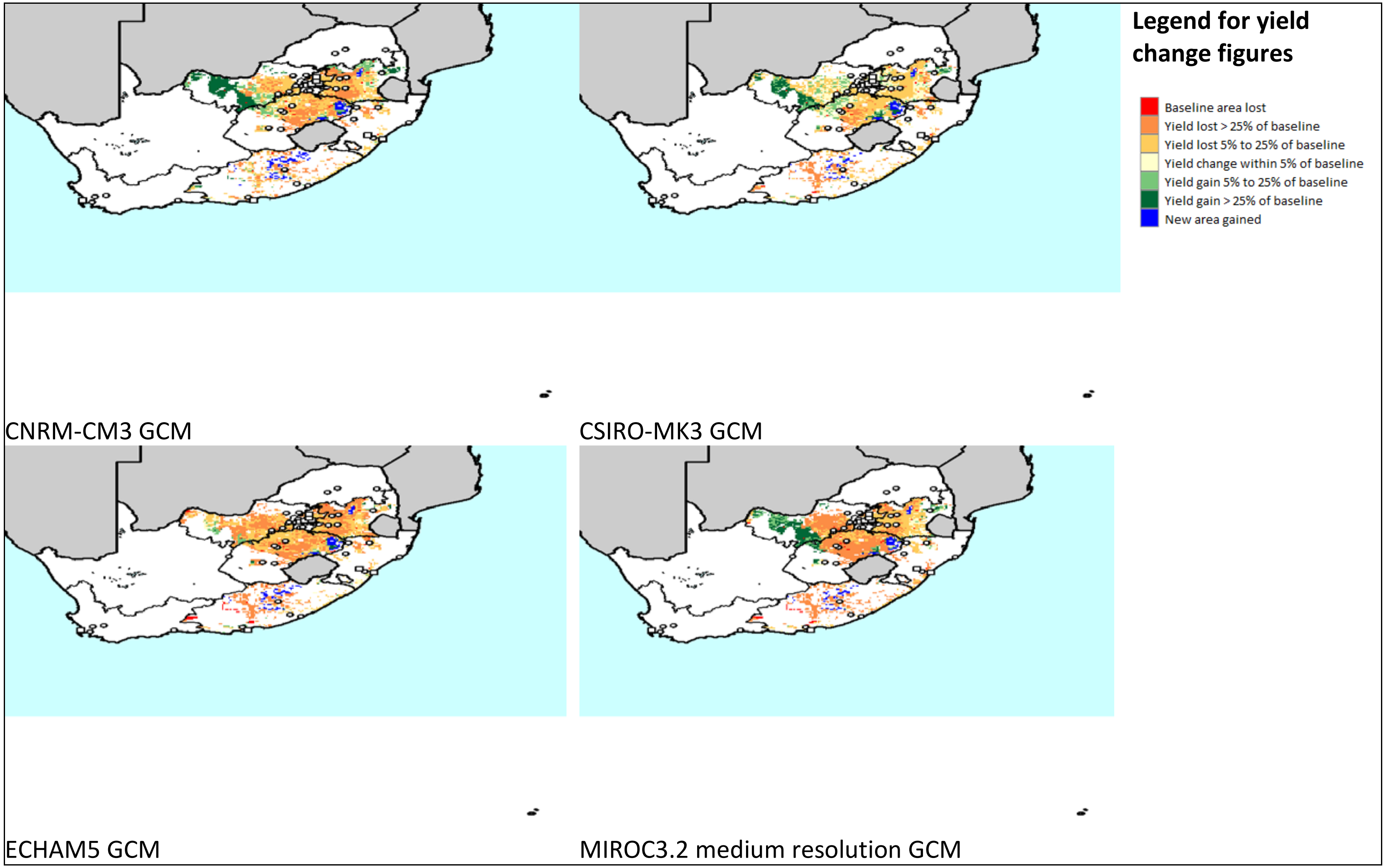


Figure 21. Yield change map under climate change scenarios: rainfed maize. Source: IFPRI.

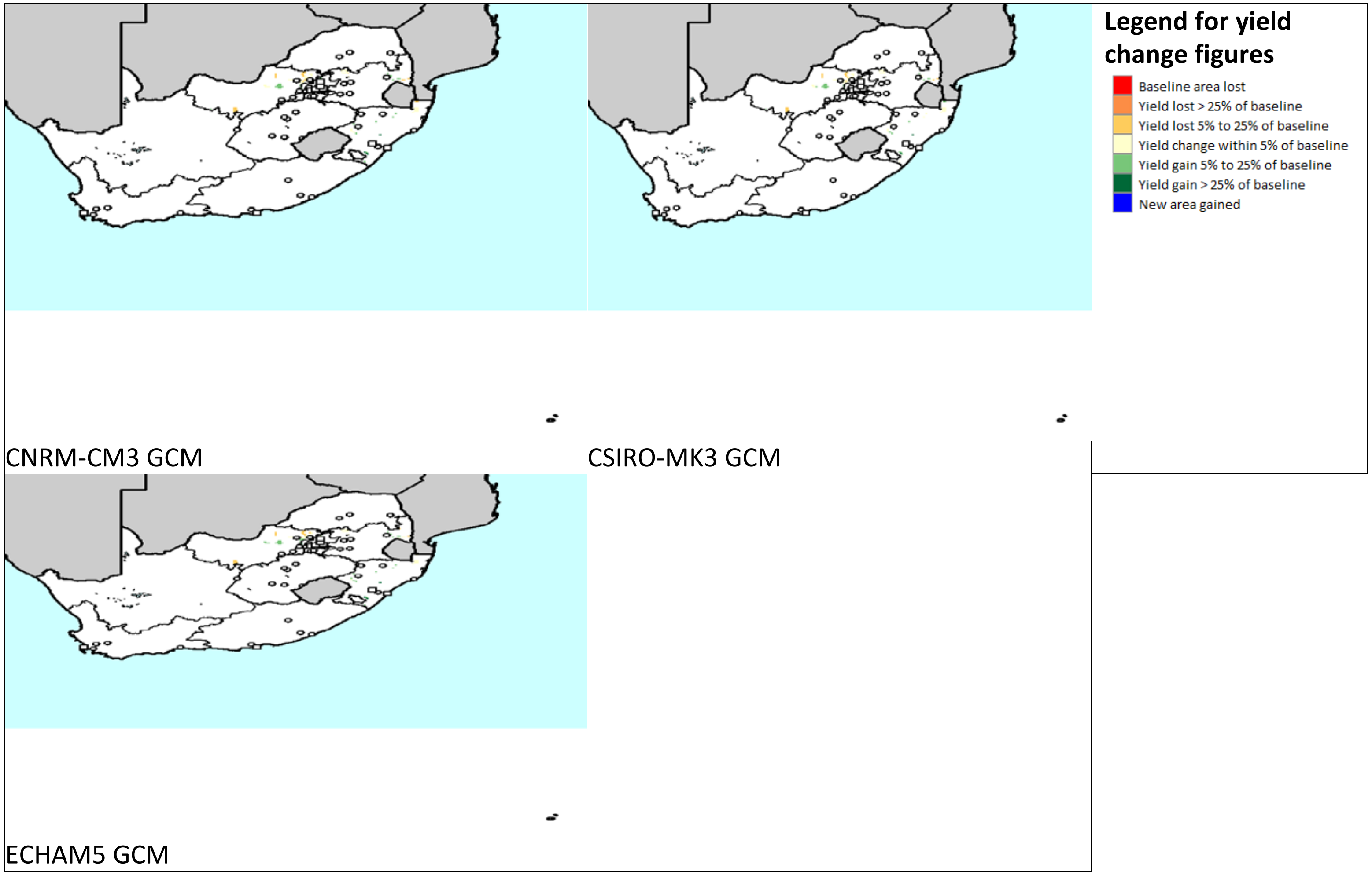


Figure 22. Yield change map under climate change scenarios: irrigated groundnuts. Source: IFPRI.

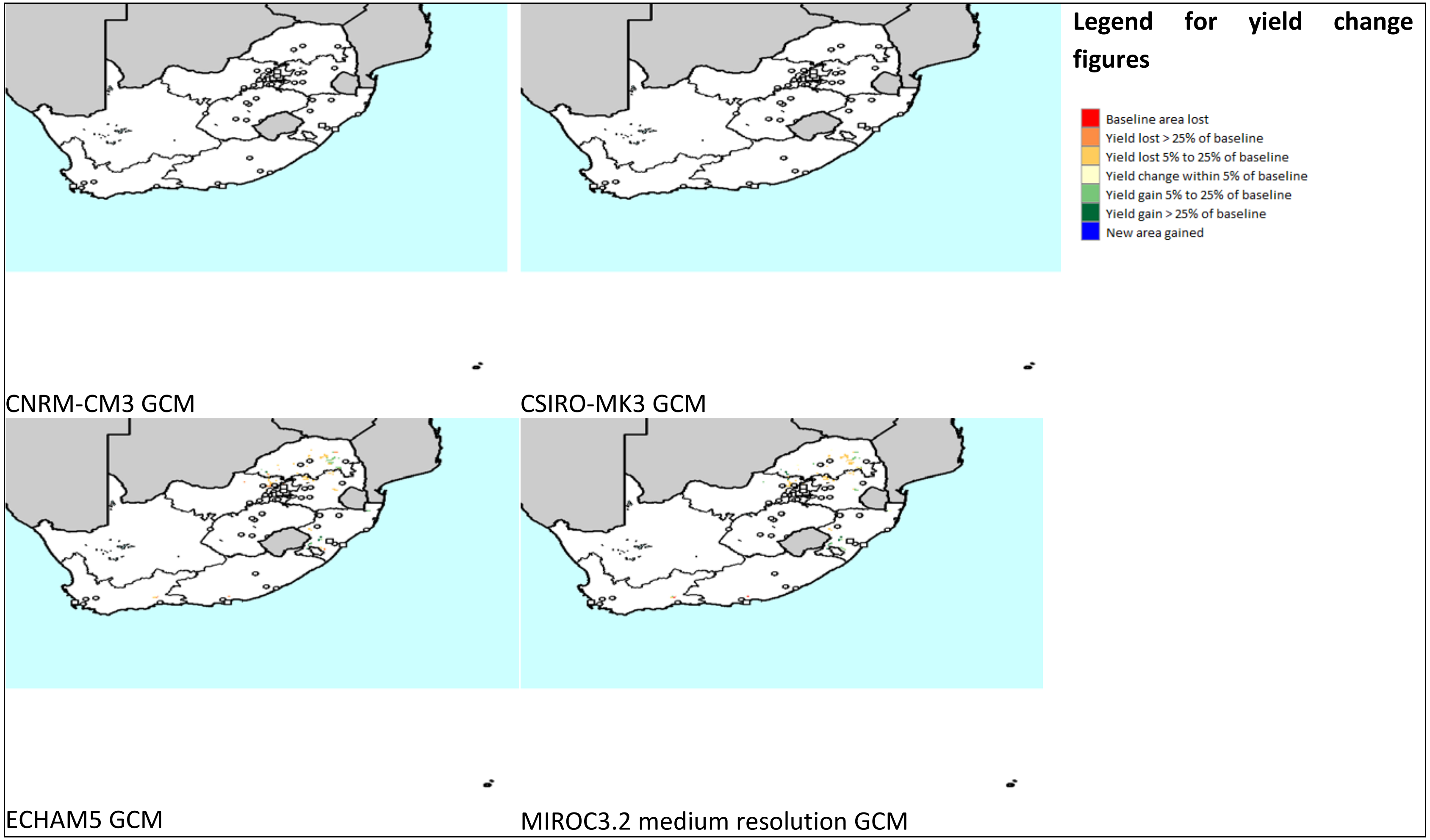


Figure 23. Yield change map under climate change scenarios: irrigated soybeans. Source: IFPRI.

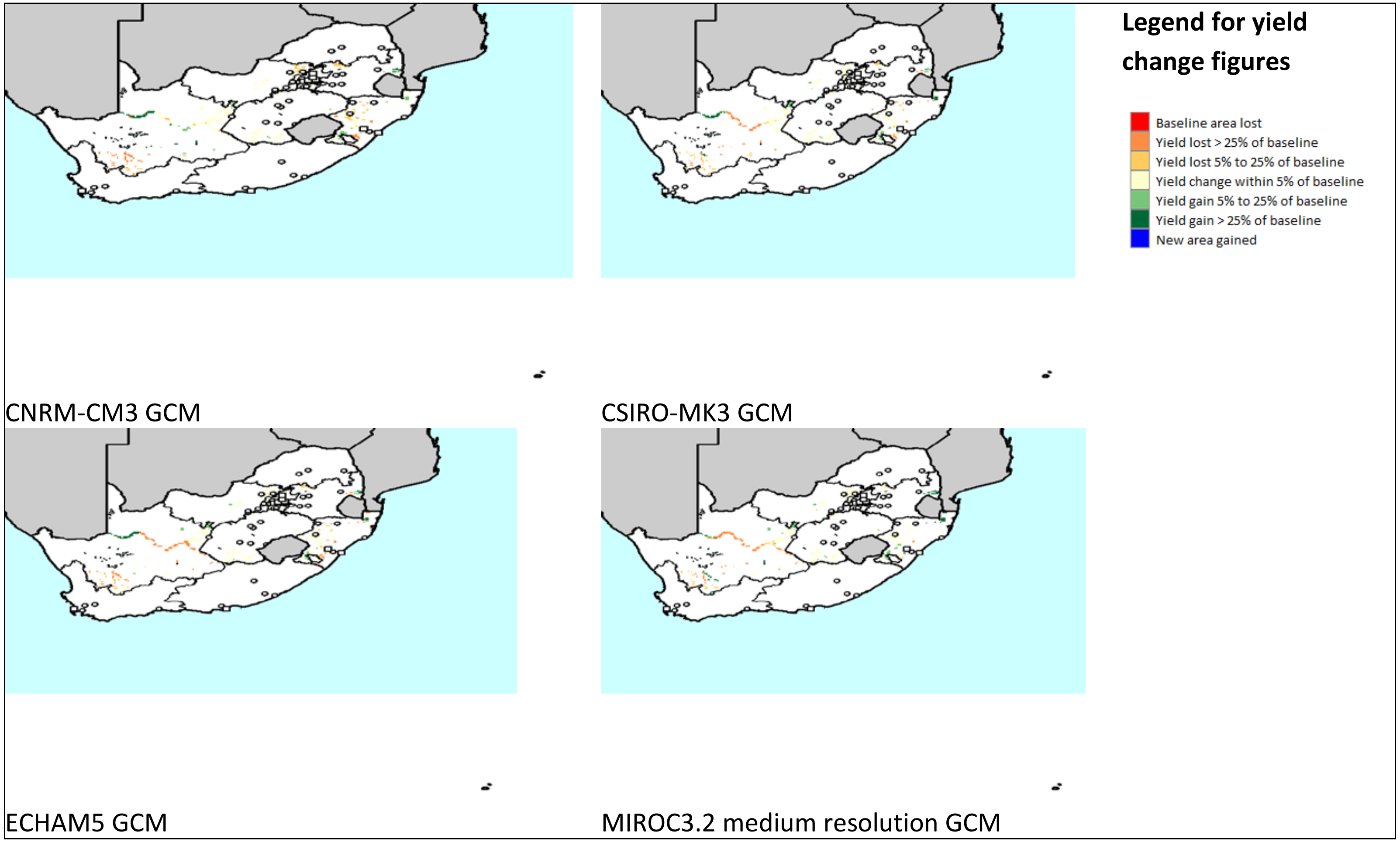


Figure 24. Yield change map under climate change scenarios: irrigated wheat. Source: IFPRI.

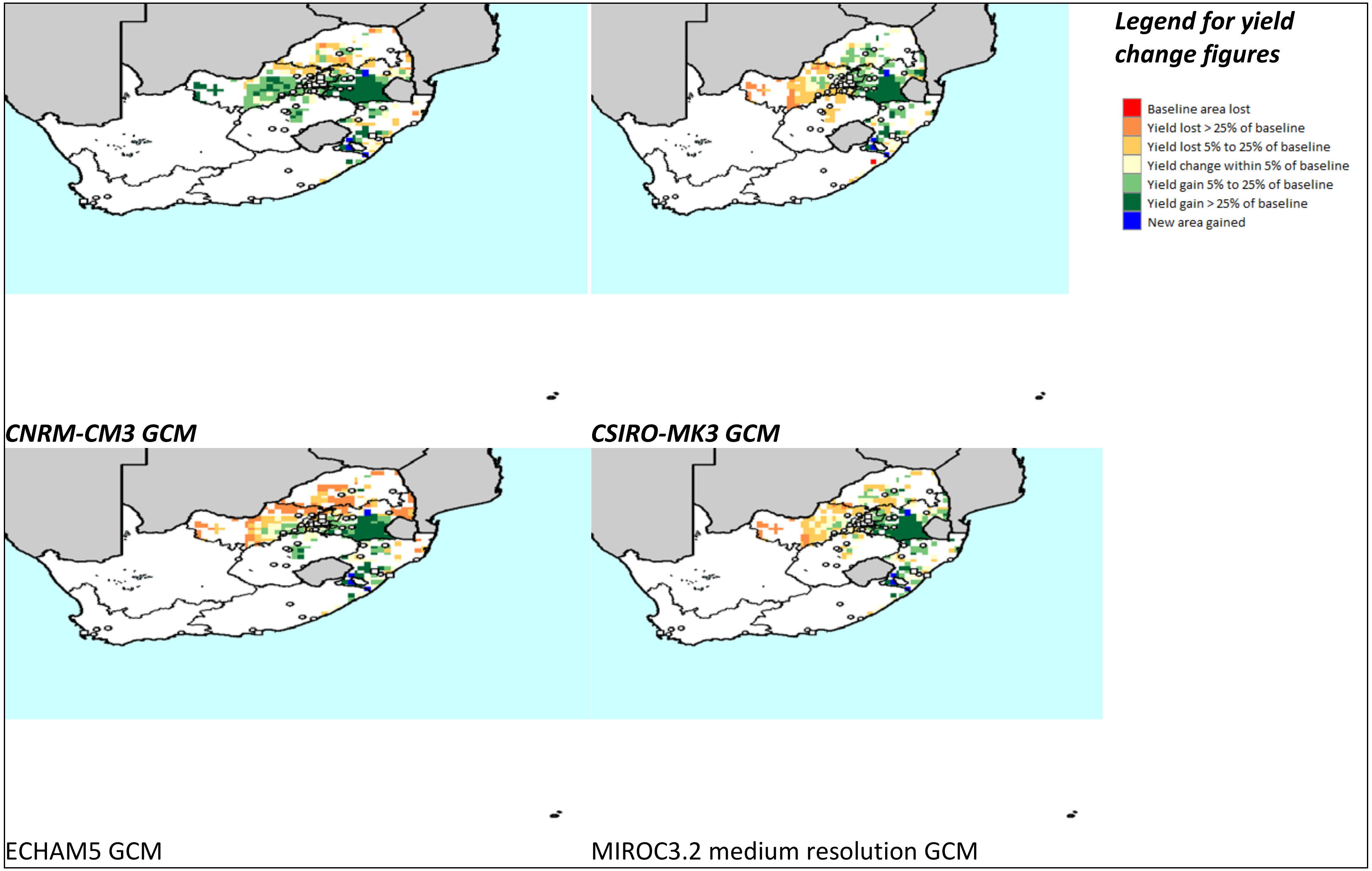


Figure 25. Yield change map under climate change scenarios: rainfed groundnuts. Source: IFPRI.

5 From Biophysical Scenarios to Socioeconomic Consequences: The IMPACT Model

Figure 26 provides a diagram of the links among the three models used in this analysis: IFPRI's IMPACT model (Cline 2008), a partial equilibrium agriculture model that emphasizes policy simulations; a hydrology model and an associated water-supply demand model incorporated into IMPACT; and the DSSAT crop modeling suite (Jones et al. 2003) that estimates yields of selected crops under varying management systems and climate change scenarios. The modeling methodology reconciles the limited spatial resolution of macro-level economic models that operate through equilibrium-driven relationships at a national level with detailed models of biophysical processes at high spatial resolution. The DSSAT system is used to simulate responses of five important crops (rice, wheat, maize, soybeans, and groundnuts) to climate, soil, and nutrient availability, at current locations based on the SPAM dataset of crop location and management techniques. This analysis is done at a spatial resolution of 15 arc minutes, or about 30 km at the equator. These results are aggregated up to the IMPACT model's 281 spatial units, called food production units (FPUs) (Figure 27). The FPUs are defined by political boundaries and major river basins.

5.1 Income and Demographic Scenarios

Differences in GDP and population growth define the overall scenarios analyzed here, with all other driver values remaining the same across the three scenarios.

Table 7 documents the GDP and population growth choices for the three overall scenarios for this analysis. Table 8 shows current and scenario annual growth rates for different regional groupings as well as for South Africa. It illustrates the path of per capita GDP growth for South Africa under these scenarios. In all scenarios, South Africa's GDP growth exceeds those of the developed group of countries and most developing countries.

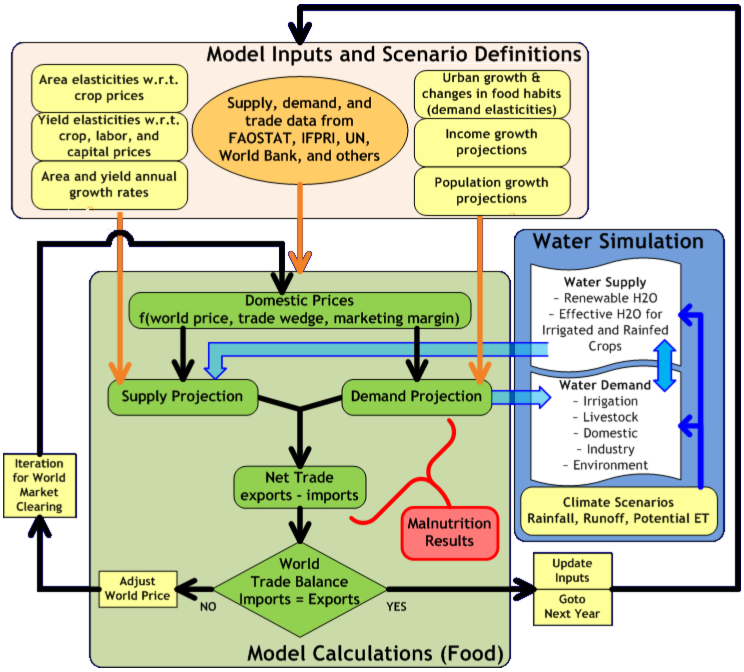


Figure 26. The IMPACT modeling framework.
Source: Nelson et al. (2010).

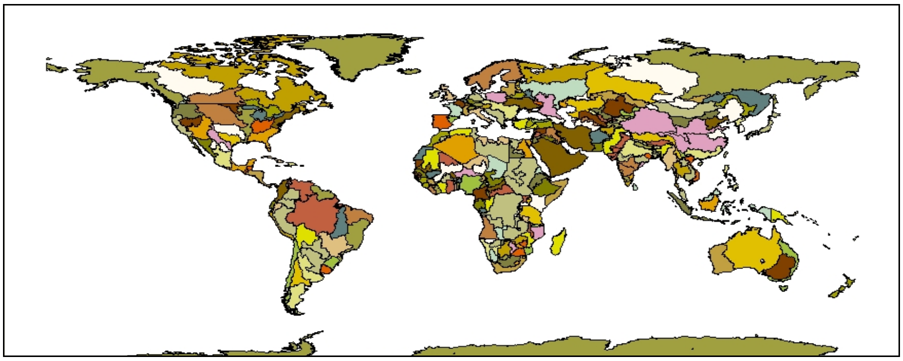


Figure 27. The 281 FPUs in the IMPACT model.
Source: Nelson et al. (2010).

Table 7. GDP and population choices for the three overall scenarios

Category	Pessimistic	Baseline	Optimistic
GDP, constant 2000 US$	Lowest of the four GDP growth rate scenarios from the Millennium Ecosystem Assessment GDP scenarios (Millennium Ecosystem Assessment 2005) *and* the rate used in the baseline (next column)	Based on rates from World Bank EACC study (Margulis 2010), updated for Sub-Saharan Africa and South Asian countries	Highest of the four GDP growth rates from the Millennium Ecosystem Assessment GDP scenarios (Millennium Ecosystem Assessment 2005) *and* the rate used in the baseline (previous column)
Population	UN High variant, 2008 revision	UN medium variant, 2008 revision	UN low variant, 2008 revision

Source: Based on analysis conducted for Nelson et al. (2010).

Table 8. Average scenario per capita GDP growth rates (percent per year)

Category	1990–2000	2010–2050		
		Pessimistic	Baseline	Optimistic
South Africa	1.64	1.18	2.75	4.12
Developed	2.7	0.74	2.17	2.56
Developing	3.9	2.09	3.86	5.00
Low-income developing	4.7	2.60	3.60	4.94
Middle-income developing	3.8	2.21	4.01	5.11
World	2.9	0.86	2.49	3.22

Source: World Development Indicators for 1990–2000 and authors' calculations for 2010–2050.

Figure 28 graphs the three GDP per capita scenario pathways; the result of combining the three GDP projections with the three population projections from the United Nations Population Office. The “optimistic scenario” combines high GDP with low population. The “baseline scenario” combines the medium GDP projection with the medium population projection. Finally, the pessimistic scenario”“ combines the low GDP projection with the high population projection.

Note that the scenarios used apply to all countries; that is, in the optimistic scenario, every country in the world is assumed to experience high GDP growth and low population growth.

The GDP per capita income scenario results for South Africa and the U.S. can be seen in Table 9. In the pessimistic scenario, U.S. per capita income increases less than 2 times while in the optimistic scenario, it almost triples between 2010 and 2050. The South African per capita income triples in the pessimistic scenario and increases almost 12 times in the optimistic scenario. However, despite South Africa’s much more rapid growth than in the U.S. its per capita income in 2050 is still only one-fifth of that in the U.S.

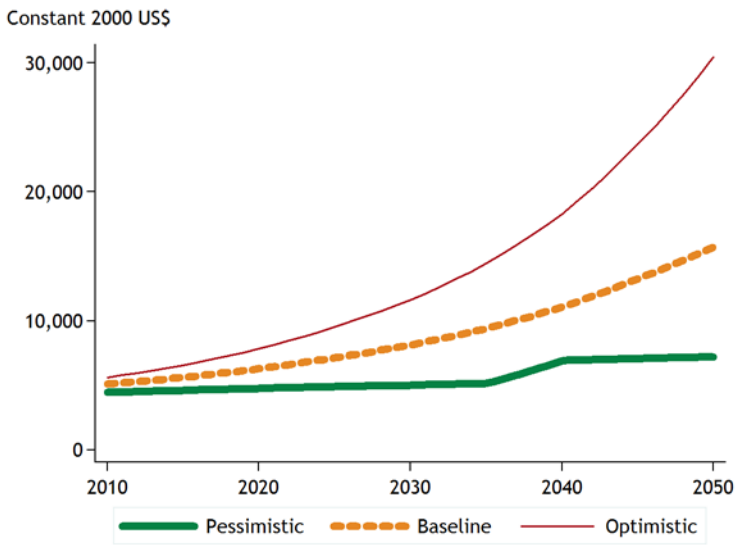


Figure 28. GDP per capita scenarios for South Africa. Source: Based on IMPACT results of July 2011, computed from World Bank and United Nations population estimates (2008 revision).

Table 9. South Africa and U.S. per capita income scenario outcomes for 2010, 2030, and 2050 (2000US$ per person)

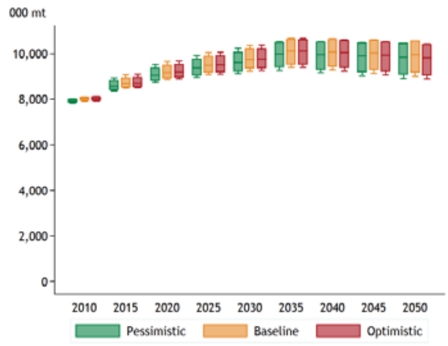
Scenario	Per Capita Income		
	2010	2030	2050
Pessimistic			
South Africa	4,441	5,006	7,202
U.S.	37,504	51,132	58,291
Baseline			
South Africa	5,105	8,128	15,740
U.S.	37,723	56,517	88,841
Optimistic			
South Africa	5,621	11,623	30,457
U.S.	39,218	67,531	101,853

5.2 Crop-specific Agricultural Vulnerability Scenarios

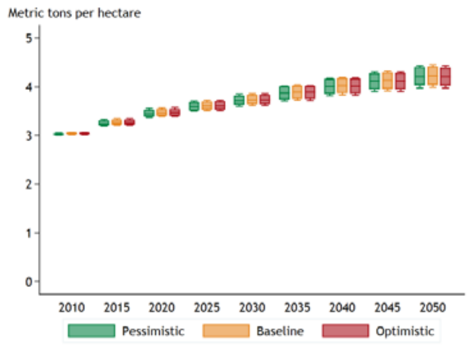
Figures 29 to 34 show simulation results from the IMPACT model for maize, wheat, groundnut, sorghum, soybeans and sugarcane. Each crop has five graphs: one each showing production, yield, area, net exports, and world price.

Several of the figures below use box-and-whisker plots to present the effects of the climate change scenarios in the context of each of the economic and demographic scenarios. Each box has 3 lines. The top line represents the 75th percentile, the middle line is the median, and the bottom line is the 25th percentile.[2]

[2] These graphs were generated using Stata with Tukey's (Tukey 1977) formula for setting the whisker values. If the interquartile range (IQR) is defined as the difference between the 75th and 25th percentiles, the top whisker is equal to the 75th percentile plus 1.5 times the IQR. The bottom whisker is equal to the 25th percentile minus 1.5 times the IQR (StataCorp 2009).

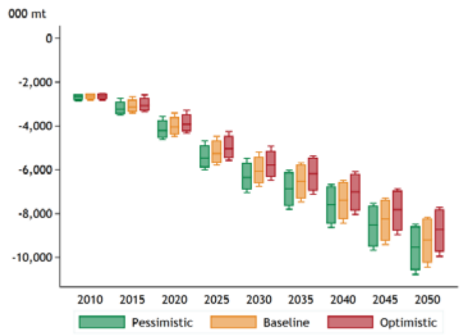


Production

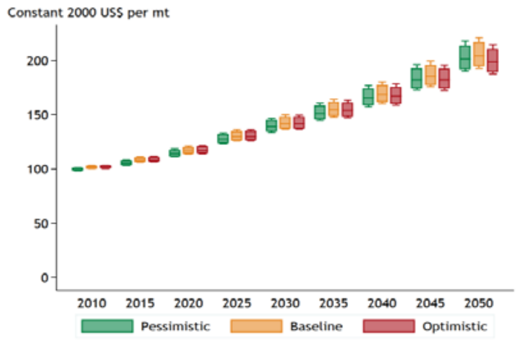


Yield

Area

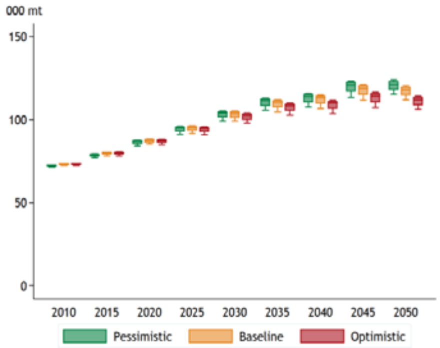


Net Exports

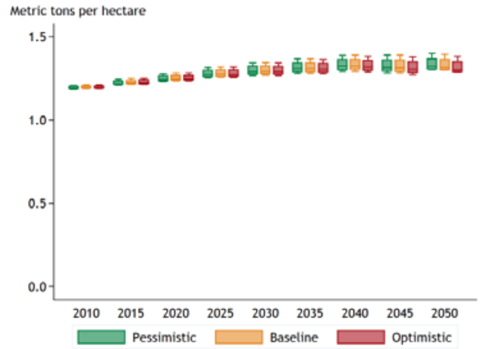


Prices

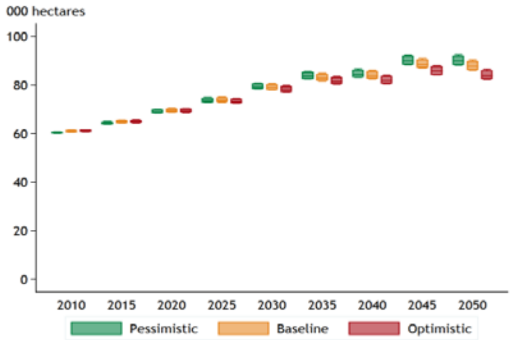
Figure 29. Scenario outcomes for maize area, yield, production, net exports, and prices. Source: Based on IMPACT results of July 2011.



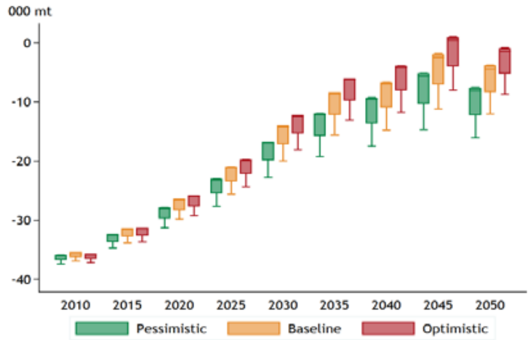
Production



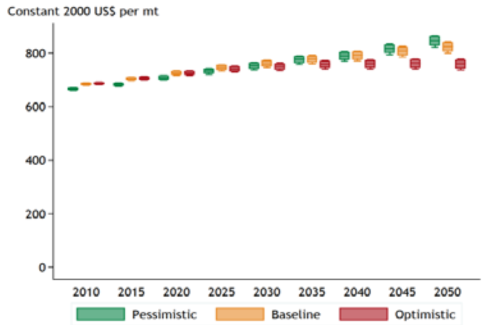
Yield



Area



Net Exports



Prices

Figure 30. Scenario outcomes for groundnuts area, yield, production, net exports, and prices. Source: Based on IMPACT results of July 2011.

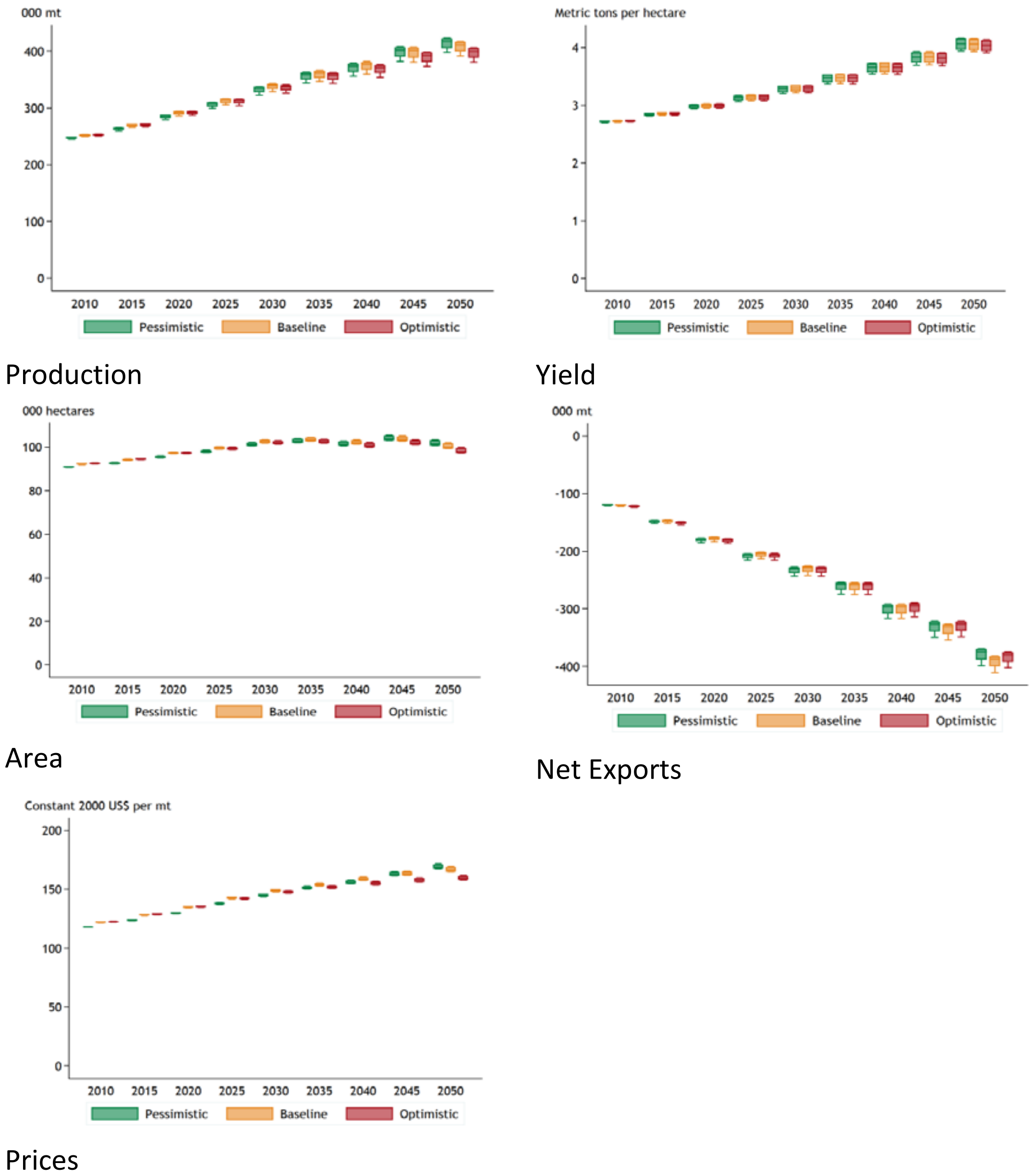


Figure 31. Scenario outcomes for sorghum area, yield, production, net exports, and prices. Source: Based on IMPACT results of July 2011.

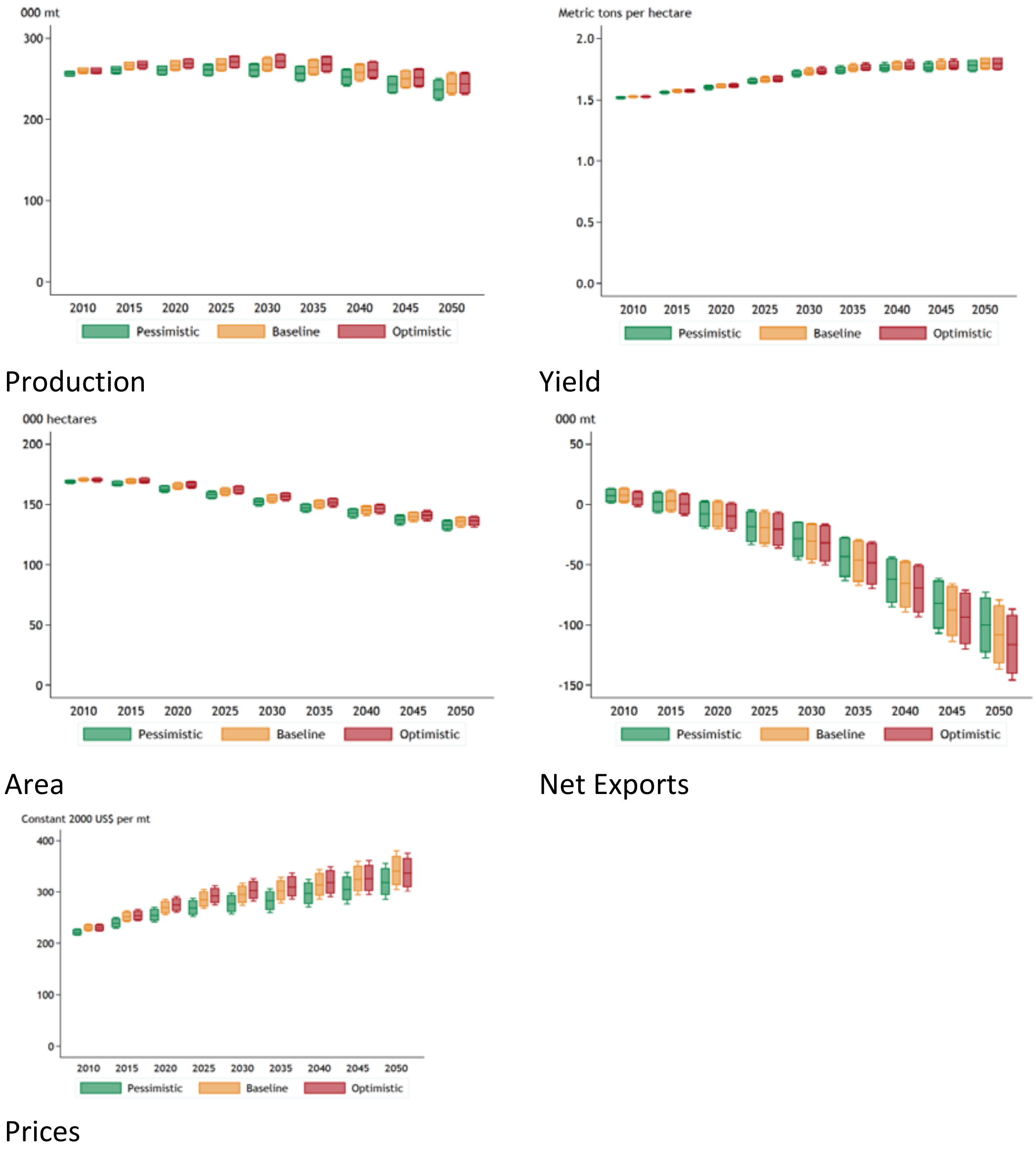
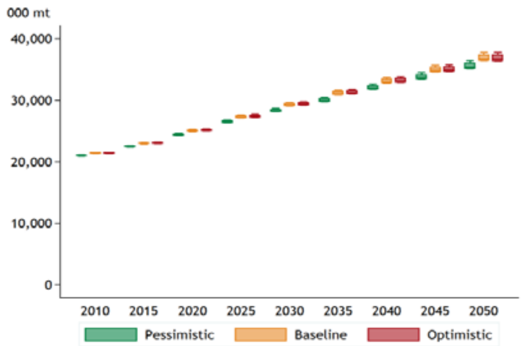
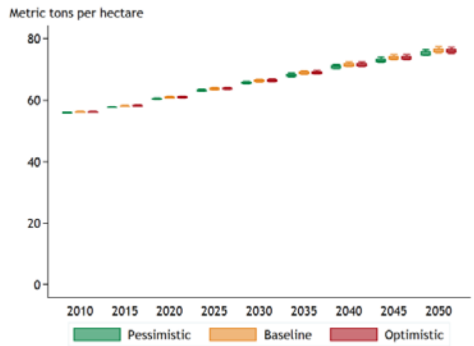


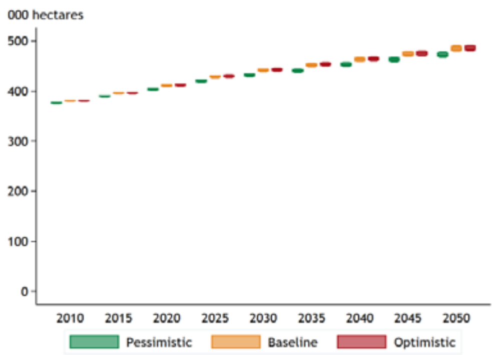
Figure 32. Scenario outcomes for soybeans area, yield, production, net exports, and prices. Source: Based on IMPACT results of July 2011.



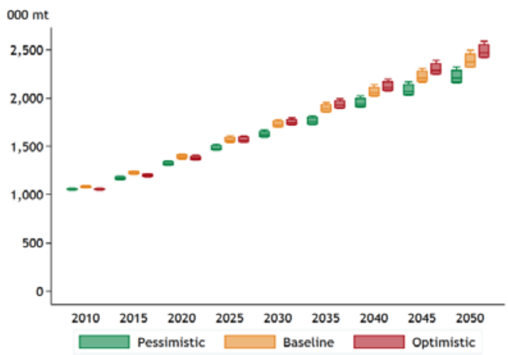
Production



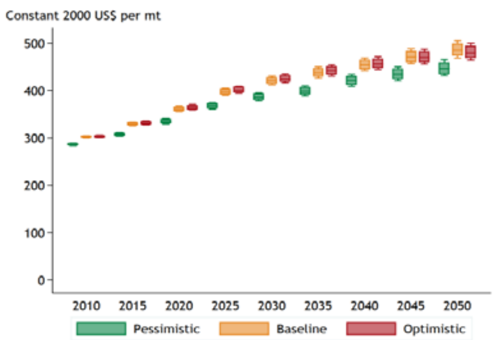
Yield



Area



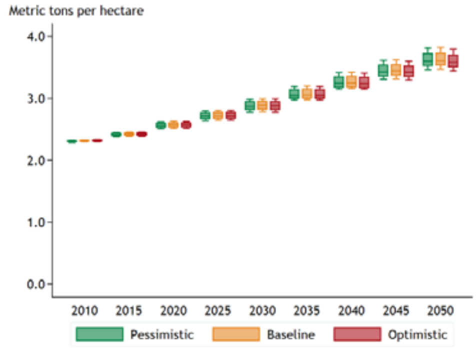
Net Exports



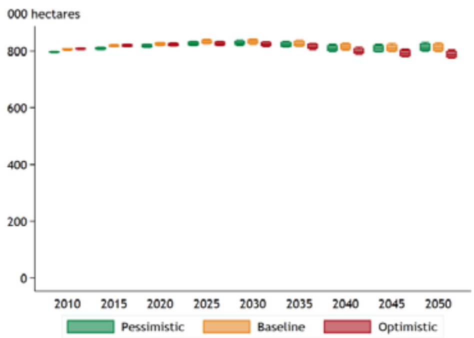
Prices

Figure 33. Scenario outcomes for sugarcane area, yield, production, net exports, and prices. Source: Based on IMPACT results of July 2011.

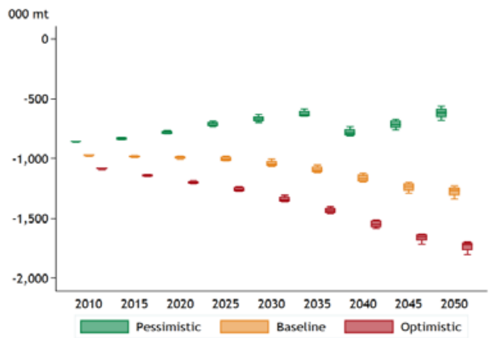
Production



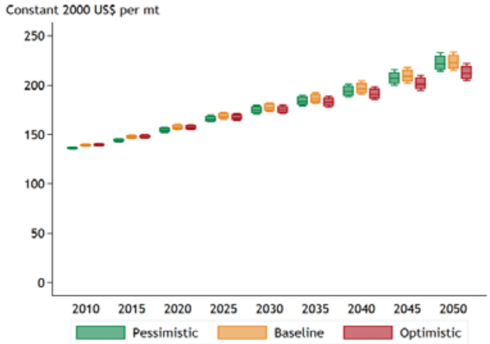
Yield



Area



Net Exports



Prices

Figure 34. Scenario outcomes for wheat area, yield, production, net exports, and prices. Source: Based on IMPACT results of July 2011.

South Africa’s maize production is projected to increase slightly from 2010 to 2050 under all scenarios, despite a projected decrease in area under cultivation from 2 800 000 hectares to about 2 100 000 hectares by 2050. Despite an increase in projected maize price during the same period net imports of maize to South Africa are projected to increase from about 20% of consumption (in these graphs, exports have a positive sign and imports a negative sign) to about 50% of consumption (Figure 29) – a national food security concern.

Groundnuts, whilst nutritionally rich, do not form a major dietary component for South Africa. Groundnuts are an important source of vegetable oil. Ground nut production is projected to increase from about 75 000 mt in 2010 to about 130 000 mt by 2050. The area under groundnut production is projected to increase by over 20% during the same period (Figure 30). Groundnuts yield, however, does not increase significantly with increase in area under cultivation.

Price and yield of Sorghum are projected to increase from 2010 to 2050, while net export decreases (i.e. imports increase, from about a quarter to half of consumption) and area under cultivation remains constant. Increases in production and yield do not lead to net export of the crop (Figure 31). Sorghum is important largely for stock feed and human consumption particularly in the rural Northern parts of the country. It can serve as a substitute for maize and tends to be more drought tolerant than maize.

Under all scenarios soybeans production is expected to remain largely constant, with yields increasing slightly from about 1500 mt/ha in 2010 to about 1800 mt/ha in 2050. Area under soybeans is expected to decrease slightly during the same period. Net imports will increase dramatically while prices for the commodity will increase by almost 60% during the same period (Figure 32).

Sugarcane production is projected to increase gradually as does the area under sugarcane production. Net export of sugar is projected to increase from 1 000 000 mt in 2010 to 2 500 000 mt by 2050. Under all scenarios there is general increase in the price of sugar (Figure 33). The dual role of sugarcane i.e. as food and source of fuel may be responsible for some of the increases in exports and prices.

South Africa's wheat production is projected under all scenarios to increase despite a constant area under wheat production. The major divergence is seen in the projected net export. Under the optimistic scenario imports will increase significantly since this assumes affordability while there is a projected decrease in imports under the pessimistic scenario, where affordability in the global market is low (Figure 34).

5.3 Human Vulnerability Scenarios Outcomes

Figure 35 and Figure 36 show scenario outcomes for the average daily kilocalories per capita and the number of malnourished children under five respectively. The story is much the same in both figures in qualitative terms. The baseline and optimistic scenarios show increases in calorie availability; the pessimistic scenario has a decline, from about 3,000 kilocalories per day in 2010 to 2,600 kilocalories per day in 2050 (which is below the nutritional guideline). Climate change has relatively little effect within an overall scenario.

In general under all scenarios there is an increase in numbers until about 2020, followed by a decrease which is faster under the optimistic scenario. As expected, the baseline and optimistic scenarios do best in reducing malnourished children. In the optimistic scenario the count drops close to zero, while with the baseline it falls from about 1.0 million children in 2010 to about 0.7 million in 2050. The pessimistic scenario is also the least desirable from the perspective of reducing malnourished children. After a slow decline to just below 1.2 million by the mid-2040s, the decline stops and the number increases slightly.

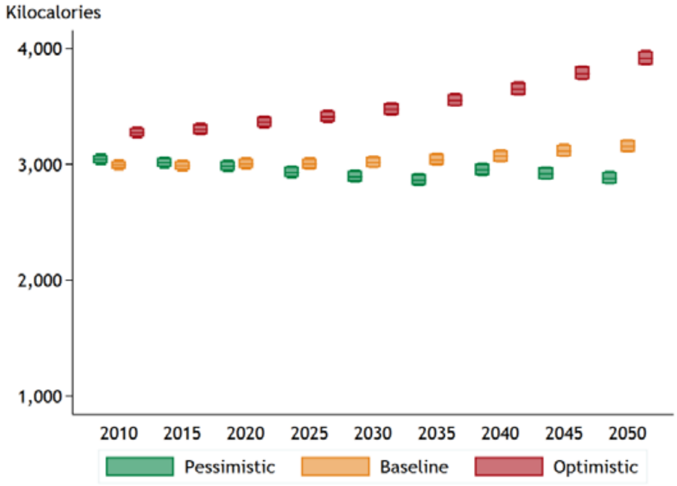


Figure 35. Average daily kilocalories availability under multiple income and climate scenarios (kilocalories per person per day) Source: Based on IMPACT results of July 2011.

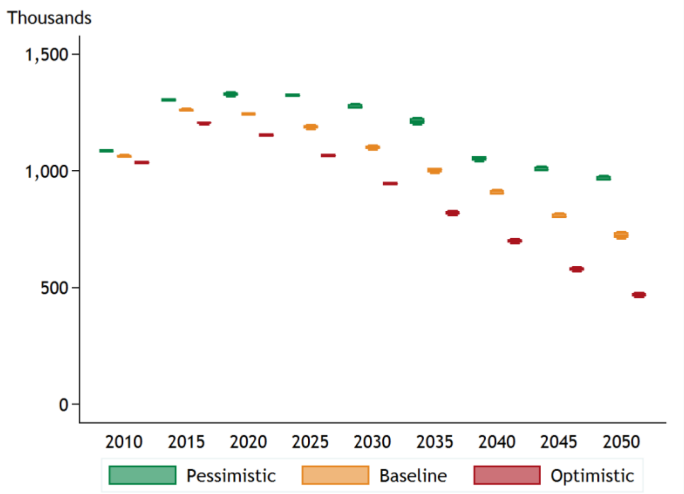


Figure 36. Number of malnourished children under 5 years of age under multiple income and climate scenarios. Source: Based on IMPACT results of July 2011.

As the box-and-whiskers plots indicate, within a particular overall scenario climate change has relatively little impact on the number of malnourished children. The range in 2050 from the different climate scenarios is typically less than 1 million children malnourished. The reason, as we discuss below, is the ability of South Africa to import and/or export depending on how climate change affects production domestically and abroad.

6 Conclusions

Climate change poses a challenge to food security in South Africa. Mitigation and adaption strategies need to be identified and implemented to avert its impacts on household food security.

Except for CNRM-CM3, all the other GCMs predict (in the AR4 runs that were available for this analysis) that South Africa will get drier during the first half of the 21st century. All GCMs predict large temperature increases for South Africa. In general GCMs predict a constrained agriculture environment for South Africa to 2050.

In general, the projected future changes in average production are relatively small despite climate change, since they are partly offset by assumptions of continued productivity gain due to crop genetics and agronomic practices. Rainfed maize is an exception, where gains of between 5 and 25% are projected in production. This is encouraging as maize forms a staple food for the majority of South Africans. However, if the maize is diverted either to animal consumption or biofuels, the result could still be a decrease in availability for human consumption.

In this analysis climate change has a much smaller impact on the number of malnourished children than the impact of socio-economic development scenarios. The reason is the assumed ability of South Africa to import food depending on how climate change affects production domestically and abroad.

It is vital that policies are put in place that will ensure the availability of imports of vital commodities, should climate change result in local deficits, and to allow easy and efficient exports in the event of a surplus. The policies may include strategies that allow easing of tariffs for imports of agriculture products such as wheat.

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